Diagenesis of the Amposta offshore oil reservoir (Spain)

Procesos diagenéticos en el reservorio del campo petrolífero offshore de Amposta (España)

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Abstract: Reservoir rocks from the Amposta oil field have been investigated to understand the fracture and vug porosity and to reconstruct the complete fluid flow history of the basin. Four main types of fracture systems (A, B, C and D) and five types of calcite cements have been clearly identified and characterised petrologically. Fractures type A and B, totally filled by calcite cement 1 (CC1) and 2 (CC2), probably correspond to early fractures developed during the Alpine compression. Fractures type C are vertical fractures developed during the Tertiary extension. Fractures type C are filled by: (a) reddish microspar calcite sediment (CS3), probably meteoric-karstic in origin, and (b) blocky calcite cement type 4 (CC4), associated with kaolinite, pyrite, barite formation and main oil migration. Fractures type D, filled with the greenish calcite sediment 5 (CS5), probably developed during a local compression, affecting and deforming the previous cements and the host rock.

Key words: Limestones, vug-fracture porosity, cementation stages, oil, Tarragona basin.

Resumen: *Se han estudiado varias muestras de la roca reservorio del campo petrolífero de Amposta con el objetivo de analizar la porosidad caverna y de fractura de la roca y reconsrtuir la historia de los fluidos que han circulado en la cuenca. Cuatro sistemas de fracturas se han indentificado (A, B, C y D) y cinco tipos de cementos de calcita han sido caracterizados petrológicamente. Las fracturas del tipo A y B, totalmente obliteradas por cemento de calcita (CC1 y CC2) se intepretan como fracturas desarrolladas tempranamente, probablemente durante la compresión Alpina. Las fracturas verticales de tipo C se formaron durante la extensión neógena. Éstas están rellenas por: (a) sedimento rojizo de calcita microsparítica (CS3), de origen meteórico, y (b) cemento de calcita blocky (CC4), asociado a la formación de caolinita, pirita, y barita y a la fase de migración del petróleo principal. Las fracturas de tipo D, obliteradas por sedimento de calcita verdoso (CS5), se intepretan como desarrolladas durante un evento de compresión local.*

Palabras clave: *Calizas, porosidad vug-de fractura, estadios de cementación, petróleo, cuenca de Tarragona.*

INTRODUCCIÓN

The Amposta oil field was discovered by Shell España in 1970; it has become a prolific mature hydrocarbon province. In the present work we talk about the origin of the fracture and vug porosity giving rise to the main oil reservoirs of the Amposta field and to reconstruct the complete fluid flow history of the basin, and the relative fluid flow timing. Samples were collected from well Amposta Marino C-2, between 1874 and 1957 m perforation depth.

GEOLOGICAL SETTING

The Amposta oil field is located in the Tarragona basin (northern Gulf of Valencia, NW Mediterranean), stretching between the eastern Iberian Peninsula and the Balearic Islands, at 22 km offshore south of the Ebro delta (Fig. 1). The Gulf of Valencia is a Neogene oil-producing basin where the accumulations are in Mesozoic and Neogene carbonates. Areal distribution of the oil fields is focused around or inside the Tarragona trough. The oil fields all occur in Amposta-type (Seeman *et al.*, 1990), mostly consisting of karsted reservoir intervals in Jurassic-Cretaceous (Casablanca, Amposta, Salmonete and Tarraco oil fields) or Lower Miocene carbonates (Dorada oil field), and paleo-high type traps.

The regional structure of the western Mediterranean area is a direct consequence of the Neogene extensional tectonic activity, which reactivated older Alpine structures. The Valencia trough, located offshore Spain, is a deep, NE-SW elongated Neogene basin. It displays a well-developed horst and graben structure (constituted by a largely deformed Paleogene-Mesozoic-Paleozoic substratum) with a thick Neogene-Quaternary sedimentary cover (up to 4 km) lying unconformably. The Amposta structure is an elongate tilted bloc of

Mesozoic carbonates (5 km long), dipping toward the ESE at 20 degrees.

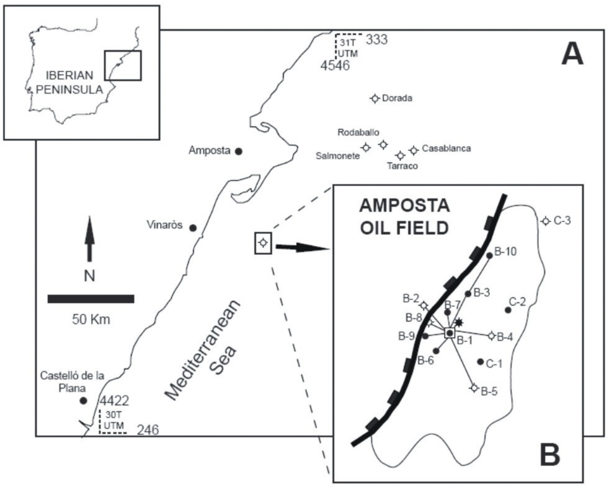

FIGURE 1. *Location of the Amposta field and of studied C-2 well.*

At 1874 to 1957 m depth, the lower Createcous host-limestones are wackestones to packstones, constituted of foraminifera, silified sponge spicules and equinoderm fragments.

FRACTURE TYPES AND CEMENTS

Four main types of fractures, filled with five main calcite cement or sediment types, affects the studied samples (Fig. 2 and 3). Each one of these infilling generations is clearly related to a specific fracture type.

Fractures type A

The fractures type A include the oldest group of fracture systems, and are totally infilled by the calcite cement 1 (CC1). These fractures appear as subvertical thin veins (1-3 mm thick) with straight borders. The CC1 is constituted by anhedric non luminescent and bright luminiscent crystals, 15-120 μm in size.

Fractures type B

The fractures type B display horizontal to subhorizontal trends and are totally infilled by the calcite cement 2 (CC2). The fractures are from less than 1mm to 3 cm thick, and with irregular borders. Horizontal to subhorizontal stylolite planes are affecting the borders of the fractures, whereas vertical to subvertical stylolitic planes ends the fracture abruptly. The CC2 is made of white to brownish anhedric to subhedric blocky crystals, non to dull red luminescent and red blue fluorescent (indistinguishable from those of the host-rock). The crystals (300 μm-2 mm in size), are not limpid and show marked exfoliation planes.

Fractures type C

The fractures type C are vertical to subvertical fractures cutting the previous ones. These fractures show sharp and undulated borders, locally enlarged by dissolution, and filled by the calcite sediment 3 (CS3) and the calcite cement 4 (CC4). Often the all fracture display cone geometry (with a maximum thickness of 2 cm) and are locally affected by stylolitic planes.

The CS3 is constituted of reddish microsparite calcite sediment, 8 to 40 μm in size, dull red luminescent and red blue fluorescent. This reddish sediment fills partially the fracture porosity with a geopetal distribution, and it is always associated towards the upper part of the fracture to CC4.

The CC4 generation is the most important volumetrically. In general, it occurs as limpid white calcite crystals, filling fracture porosity. After a corrosive event affecting this CC4, oil appears always related to this cement generation. It is composed of two cementation stages: i) Subhedric to euhedric calcite crystals, with an isopachous-rim disposition, 15 to 80 μm in size and with orange-bright luminescence; when the crystals are big enough display a dark nucleus (non luminescent) and a whiter outer zone (orange to yellow-bright luminescent). ii) Anhedric to subhedric calcite crystals with blocky texture and dull red luminescent under CL microscope; crystals are 0.6 to 1 mm in size and are occasionally zoned with a dark nucleus (dull red luminescent) and a whiter outer zone (dull orange to yellow luminescent). Both of them show red blue fluorescence.

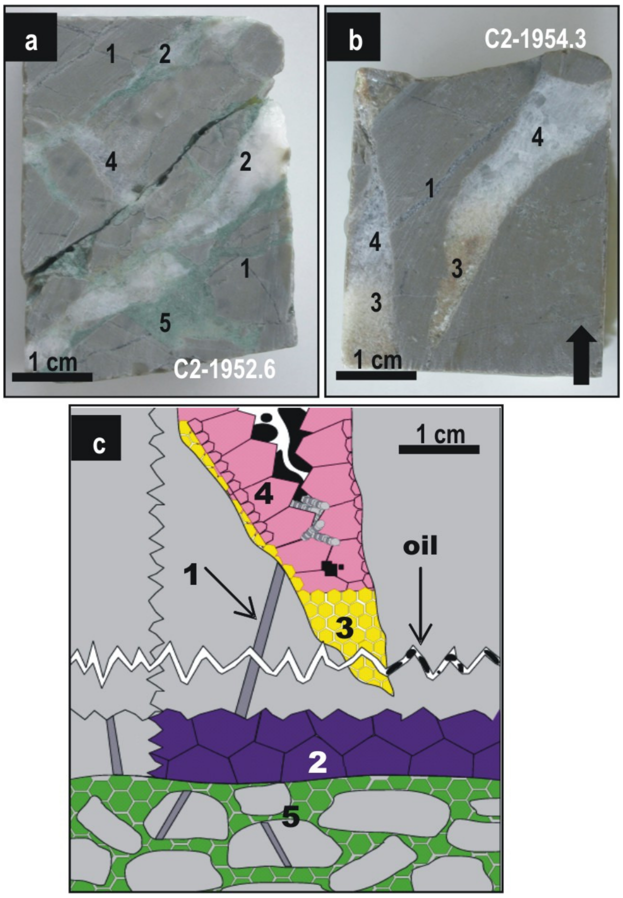

FIGURE 2. *Fotomicrograph (a,b) and synthetic sketch (c) of fractures, cements, stylolites and oil relationships. 1, CC1 filling fractures type A; 2, CC2 filling fractures type B; 3, CS3 and 4, CC4 (both filling fractures type C); 5, CS5 filling fractures type D.*

Oil, kaolinite, barite and pyrite are frequently associated to the CC4. Oil appears as a non-luminiscent and brown-fluorescent matherial. It mainly occurs in partially occluded fractures type C, but also in stylolites and in the host limestones. When oil impregnates the host rock, it is present only close to fractures planes (which also contains oil), indicating that oil circulated preferentially along the fractures. Kaolinite appears with the typical book-sheet texture, bright blue under CL microscope and with bright white fluorescence. It is commonly impregnated by oil. The CC4 crystals display a corroded-like contact with the kaolinite. Barite occurs very locally as prismatic crystals forming aggregates, apparently located in the intercrystalline porosity of CC4. Pyrite occurs as millimetric crystal aggregates, 1-2 mm in size. Occasionally, they show pseudo-skeletal habit and include calcite cements 4 and 5, indicating that they precipitated earlier than pyrite.

Fractures type D

The fractures type D are horizontal to subhorizontal fractures with totally irregular borders. These fractures do not appear isolated; they are always affecting and deforming previous fracture planes, such as the horizontal or the vertical ones. These fracture planes are filled with characteristic greenish calcite sediment 5 (CS5). This sediment is constituted by subhedric to anhedric crystals, 8 to 40 µm in size, dull orange luminescence and red blue fluorescence. Clasts of host-limestones are usually incorporated into the cement.

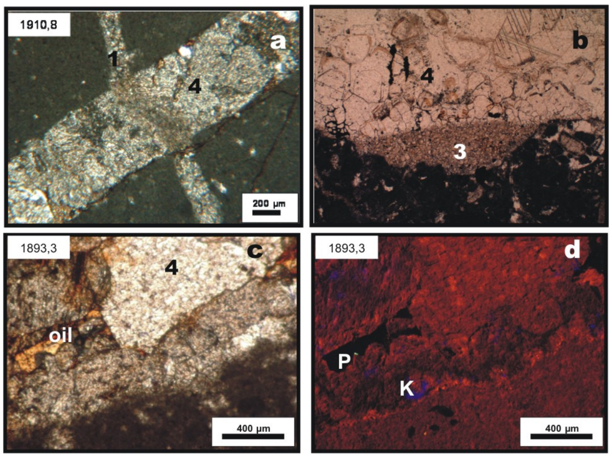

FIGURE 3. *Fotomicrograph of fractures, cements and oil relationships under plane polarised light (a, b, c) and cathodoluminiscence (d). Legend on Fig. 2. P, porosity; K, kaolinite.*

DISCUSSION AND CONCLUSIONS

Diagenetic evolution

Early development of fractures type A and cementation by CC1 was followed by development of horizontal fractures type B, probably during the late Eocene-earlier Oligocene Alpine compression, and cementation by blocky CC2, which completely occluded the fracture porosity. Vertical fractures type C were created during the late Oligocene-early Miocene Neogene extension.

The Mesozoic/Tertiary unconformity in western mediterranean region, which is a composite surface formed by a superposition of several Palaeogene and Miocene unconformities, developed as a post-tectonic unconformity after the main phase of the Late Alpine orogeny (Esteban 1991). The Mesozoic limestones were partially subaerially exposed and intensively affected by kartification both in the onshore and offshore areas. Good preserved examples of this karstic erosion have been described in the neighbouring Casablanca oil field (Esteban 1991; Lomando *et al*., 1993) and in the offshore Catalan Coastal Ranges (Klimowitz *et al*., 2005). Karstic dissolution in the studied samples occurs in the fractures type C. Circulation of corrosive fluids along this fractures in the Amposta area enlarged the fracture walls and produced vugs and microcaves (Fig. 3B). The reddish microspar calcite CS3 represents the detrital karstic deposits partially filling fracture C porosity, previously enlarged by dissolution. Observed dissolution processes in the studied samples are compatible with the total losses of the boreholes (which imply big caves up to 2 m diameter). The initial porosity developed during meteoric karstification was partially filled by cements (blocky CC4) precipitated from upward migrating fluids in the karstic system. Precipitation of CC4 would have reduced, but not totally occluded, the fracture C porosity.

Main oil migration took place clearly related to CC4, which partially occluded the vertical to subvertical fractures type C (Fig. 4). No oil-evidences exist in the CC5. Oil circulates in non cemented fracture planes and in the intercrystalline porosity and the exfoliation planes of CC4. Partial corrosion of CC4 occurs during oil migration. Oil is also associated with kaolinitization processes, and minor corrosive event affecting CC4 has been observed in the cement-oil, cement-kaolinite or cement-kaolinite-oil (when kaolinite is oil-wet) contacts. Kaolinite, pyrite, barite, and other accompanying minerals occurs after (or partially coeval) this corrosion. Late corrosion porosity is usually associated with minor volumes of mineral precipitates such as found, together with dickite, quartz, gypsum, calcite, fluorite, etc. (Rossi *et al*., 2001). These precipitates can be formed prior or during the arrival of hydrocarbons, and are related to the main oil migration. Taking into account that oil from Amposta field is sulphur-rich (5%) and that source rock are the Upper Jurassic carbonates from Ascla Fm (Permanyer and Salas 2005) interpreted as being deposited in relatively reducing conditions favouring sulphate-reduction.

Development of horizontal to subhorizontal fracture zones type D probably occurred during a late Langhian-early Serravallian local compression, with the formation of vertical stylolites and opening of preexisting horizontal stylolitic planes. The porosity in the fracture zone is rapidly obliterated by precipitation of the greenish CS5 and also by host rock and earlier cement fragments which are incorporated in the fracture. The CS5 event reflects the return to meteoric dominated karstic system. Although it is still an unresolved question, it could be a detrital karstic deposit (Esteban, pers. com.) or fracture-zones with highly fractured cements and host rock.

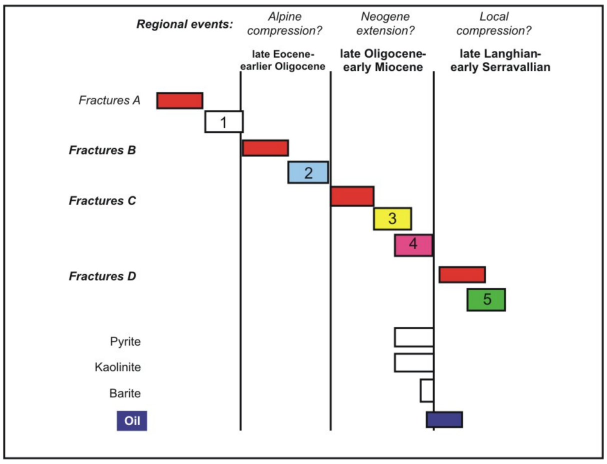

FIGURE 4. *Diagenetic evolution of the Amposta oil reservoir rocks. 1, CC1; 2, CC2; 3, CS3; 4, CC4; 5, CS5.*

Source rocks and oil migration

When the burial depth and heat flow reached suitable levels, the oil began to migrate; expulsion occurred in late Miocene-early Pliocene times in the Tarragona trough (Clavell y Berastegui 1991; Varela *et al*., 2005). Nevertheless, these authors only consider that the oil-fields in the Tarragona area were sourced from the early Miocene Casablanca Shales Fm. Since the Kimmerdidgian Ascla Fm has been proved as the oil source-rock for the Amposta oil field (Permanyer y Salas 2005), additional chronological ideas must be considered for the oil charge. The Ascla Fm entered the oil window at 90 My (Turonian; Permanyer y Salas 2005). Oil migration history of the Ascla Limestones and Marls Fm was studied by Rossi *et al.* (2001) in the onshore setting, concluding that the paragenetic sequence and burial evolution are consistent with oil generation when the Ascla was at or close to maximum burial depth, but before the Eocene Alpine tectonism, which formed the structural traps in the Maestrat basin; oil generation and migration through fractures occurred long before this event, very likely during the Late Cretaceous to earliest Tertiary. Nevertheless, the age of trap and seal in the Amposta oil field is Miocene, when the area experienced and important rifting phase. A second phase of oil generation from the Ascla Fm has been suggested due to the Miocene subsidence, on the basis of the burial and thermal model of the Amposta Marino C-3 well (Permanyer & Salas 2005). The diagenetic sequence of the well Amposta Marino C-2 indicates that oil emplacement took place later to the opening of the Neogene extensional fractures (Fig. 4). The proposed second organic matter maduration phase of the Kimmeridgian Ascla source-rock in the offshore setting at Miocene times can be the responsible of the final oil charge in the Cretaceous reservoir-limestones from the Amposta oil field.

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