K030

Fault-associated Dolomites in the Benicàssim Area, Maestrat Basin, E. Spain - Macro- to Micro-scale Fluid Flow in Carbon

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SUMMARY

Partial dolomitization of the middle to late Aptian carbonate succession from the SE Maestrat Basin (E. Spain) occurred during shallow burial in relation to the circulation of high temperature fluids (>60º C) through regional extensional faults and most permeable host limestone facies. The timing of replacement is constrained between the early Albian (syn-rift) and the Campanian (post-rift). Analytical data suggest that most likely dolomitizing fluid is evolved Aptian/Albian seawater, probably mixed with basinal waters. The resulting replacive dolomite texture has very low porosity, mainly of vuggy type, that was successively enhanced by dissolution and occluded by burial dolomite and calcite cementation during Late Cretaceous. Dolomite hosted Mississipi Valley-type ore deposits, and associated saddle dolomite, formed due to hydrothermal alteration through large-scale faults during the onset of the Tertiary. Later Alpine uplift and fracturing promote meteoric calcite cementation and dedolomitization through fractures and fault zones. Porosity and permeability data evidence a very bad potential reservoir quality of the host limestone, being only slightly higher in the dolomites due to the reported pervasive burial calcite cementation. Results provide a new case study of partial dolomitization that can be used in the characterization of equivalent hydrocarbon reservoirs worldwide.

Introduction

Numerous hydrocarbon reservoirs occur in partially to completely dolomitized carbonate sequences, and thus the study of equivalent outcrop analogs is important for subsurface reservoir characterization. Especially important are those uncertainties about the origin of reservoir quality variability in dolomites closely associated with fractures.
Extensive exposures of the lower Cretaceous succession in the Benicàssim area (SE Maestrat Basin, E Spain) allow characterizing a seismic- to subseismic-scale dolomitization of marine carbonates closely associated with the fault system. The purpose of this work is to highlight the most important field and analytical data from the Benicàssim case study, and to report a new outcrop analog for partially dolomitized carbonate reservoirs worldwide.

Early Cretaceous carbonates

The lower Cretaceous sediments of the Benicàssim area consists of more than 2000 m of shallow marine carbonates deposited during the Upper Jurassic-Early Cretaceous rift of the Maestrat Basin (Salas et al., 2001). The Middle to Late Aptian, possibly to Early Albian, Benassal Formation forms a ~1500 m carbonate succession stacked in three transgressive-regressive sequences (Bover-Arnal et al., 2009). The succession represents basin/outer to inner ramp environments characterized by the typical Urgonian fauna (rudist, orbitolina, calcareous algae and coral). The Benassal Fm is partially dolomitized, locally hosting Mississippi Valley-type (MVT) ore deposits (Fig. 1).

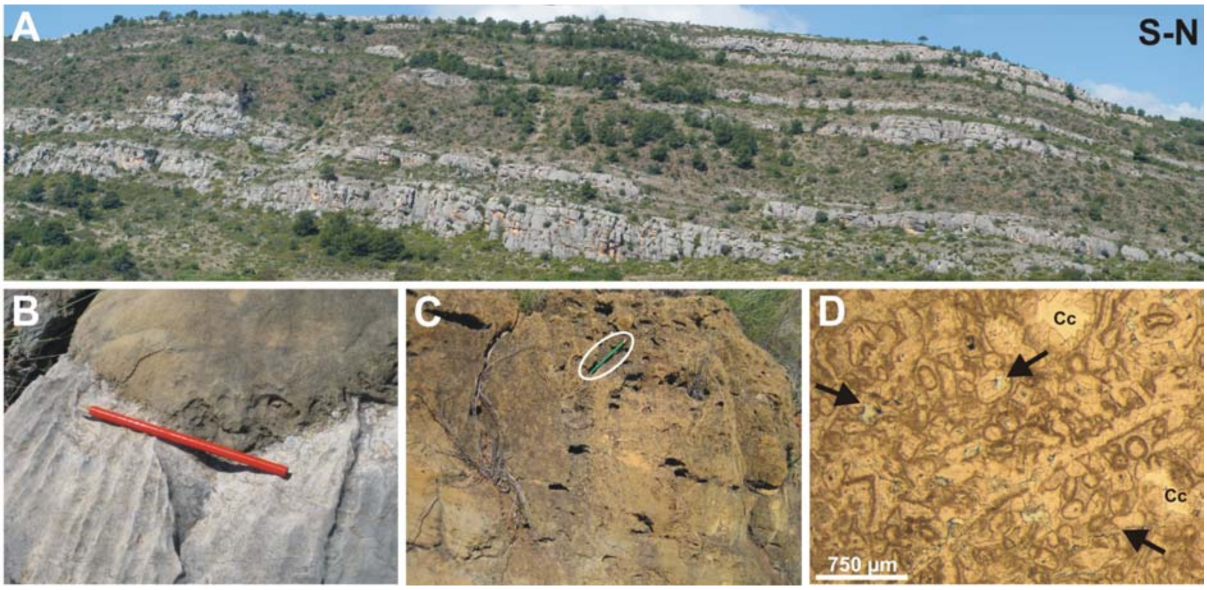

Figure1 *(A) Field view showing the spatial relationship between the host limestone beds (grey) and the dolomite bodies (brown). The view is about 1 km long; (B) Typical sharp wavy contact (dolomitizing front) between the host limestone and the dolomite. The pencil is 15 cm long; (C) Outcrop view of a brown color dolomite showing preserved sedimentary lamination. The pencil is 15 cm long; (D) Reflected light photomicrograph of replacive dolomite showing very low intercrystalline porosity (arrows) and the original grainstone fabric. Calcite cement (Cc).*

Structure and burial history

The syn-rift Early Cretaceous extensional faults that characterize the Benicàssim area form two regional sets of fractures (SW-NE and NW-SE), along with subordinated fractures, that were subsequently reactivated during the Alpine compression and during the Neogene extension. These large normal faults reach vertical displacements of kilometric-scale, leading to lateral stratigraphic contact between the Early Cretaceous succession and the metamorphic carboniferous basement, the

Permo-Triassic red beds and dolomites, and the Jurassic limestones and dolomites (Fig. 2). The Benassal Fm is overlain by the deltaic-estuarine, clay-bearing deposits of the Escucha Fm (Salas et al., 2001), which is interpreted to represent a regional seal for dolomitizing fluids.

Both dolomites and MVT deposits are located in close proximity to regional faults, suggesting that these structures were a common conduit for dolomitizing and mineralizing fluids. Dates for the dolomite-hosted MVT ore deposits of the southern Maestrat Basin give an Early Paleocene model age (U-Pb; Grandia, 2002), constraining the timing of dolomitization between the early Albian (end of deposition) and the onset of the Tertiary (post-rift stage). The calculated geothermal gradient during the Late Jurassic-Early Cretaceous rifting is 30-35º C/km (Caja et al., 2009); thus the maximum temperature reached by the dolomitized carbonate host rocks due to rift activity was below 60º C (<1000 m), if other heat sources are not invoked (Fig. 2).

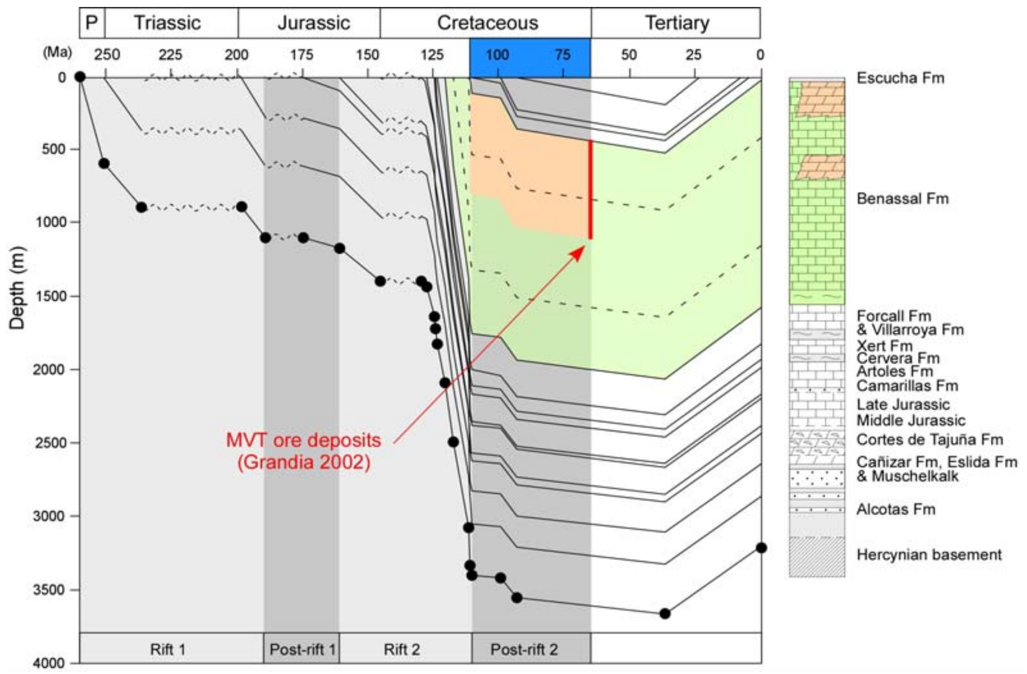

Figure 2 *Mesozoic decompacted subsidence curves showing the burial history of the lower Cretaceous Benassal Fm and the most probable dolomitzation time-span (blue area). Undulating dashed lines correspond to gaps (erosion or non-deposition). Rift and post-rift cycles interpreted according to Salas et al. (2001).*

Dolomite geometry and distribution

The most important dolomitized interval is located in the top of the Benassal Fm forming a stratiform to substratiform, brown to grey color body up to 200-m-thick within the host limestone succession (Fig. 1). This tabular body extends over several thousand square meters, suggesting a dolomitization process with a strong lateral fluid flow component. Replacive dolomite dominantly recrystallizes grain-dominated facies (skeletal and peloidal packstones to grainstones) from the top of the sequence, and also minor mud-dominated facies (skeletal and orbitolinid wackestones). Undolomitized limestones beds formed by very low porosity muddy facies (spicule mudstone to wackestones), occur within the dolomite bodies (Fig. 1).

Petrology and geochemistry

The paragenetic sequence is synthesized as follows: (1) early marine calcite cements; (2) mechanical compaction and fracturing; (3) dolomite cement; (4) replacement of the host limestone; (5) dissolution; (6) planar dolomite cement; (7) burial calcite cement; (8) fracturing; (9) saddle dolomite cement and MVT mineralization; (10) uplift and fracturing; and (11) dedolomite and meteoric calcite cement.

The early stage of compaction and fracturing, that generated vertical to sub-vertical cracks in the carbonate succession, is most probably related to the late stage Albian syn-rift. These fine cracks are most abundant in skeletal wackestone/packestone facies where fractures seem to be easily transmitted along the external wall of large bioclasts. Dolomite cement completely fills intergranular porosity in grainstones and mud-lean packstones from the top of the sequence and probably represents the early stage of dolomitization. Replacive dolomite, which form about 90% of the dolomite, occurs as transitional planar-s to nonplanar crystal mosaics suggesting dolomitization temperatures above 50-60º C (Gregg and Sibley, 1984). The resulting tight replacive texture, mainly inherited from the precursor host limestone, has a very low porosity mostly constituted by patchily distributed sub-millimeter vugs (Fig. 1D).

The most important dissolution event took place after replacement, predating the formation of clear planar dolomite (overgrowths) around cloudy, replacive centers. Dissolution affects the remaining bioclasts and created abundant secondary mouldic porosity in dolomites and limestone beds. The newly generated pore-space was dramatically reduced by burial calcite cementation. Hydrothermal fluids, associated with saddle dolomite and sulphide mineral formation during the early Tertiary altered previous dolomite textures in the vicinity of large-scale faults. Following the Alpine uplift and fracturing meteoric calcite cement and dedolomite formed preferentially along faults and fracture zones. Even though there was associated cementation, dedolomitization resulted in an overall increase in porosity, which was especially pervasive in the vicinity of fractures zones.

$\delta^{18}O$ values of dolomites and burial calcite cements indicate precipitation from a relatively high temperature fluid (Fig. 3). Fluid inclusion homogenization temperatures (T_h) of burial calcite cements range between 125º C and 160º C, which are in good agreement with previous reported data from the southern Maestrat Basin (Grandia 2002; Nadal, 2001). Replacive dolomite $^{87}Sr/^{86}Sr$ isotope values indicate that the most likely dolomitization fluid was Aptian and/or Albian seawater, probably mixed with radiogenic K-rich fluids of basinal and/or nonsedimentary origin (Grandia, 2002; Gomez-Rivas et al., 2010). The high Fe and Mn concentrations of all dolomites support part of the fluids coming from or circulated through siliciclastics sediments (basement and/or Permo-Triassic red beds).

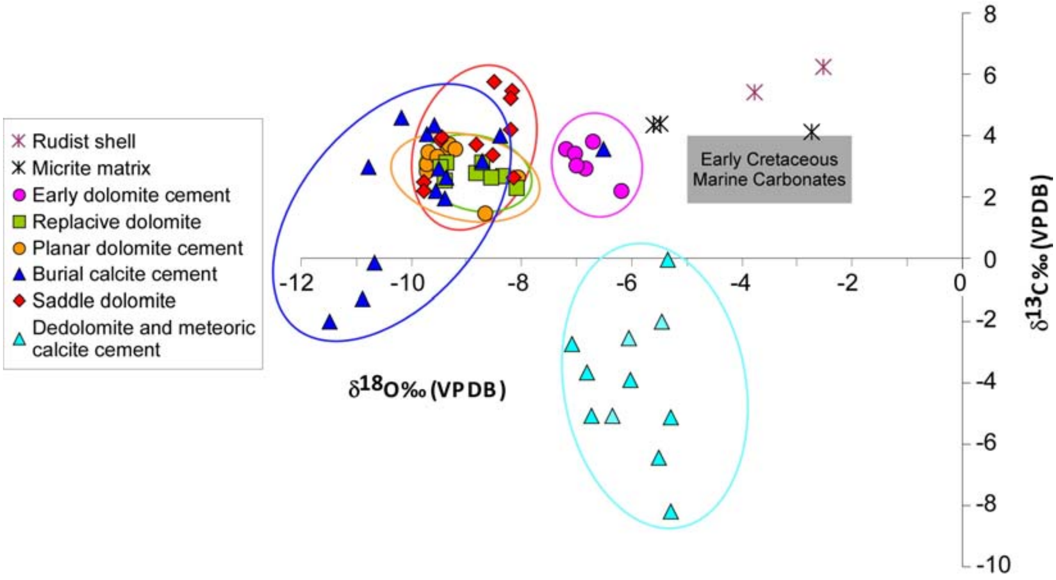

Figure 3 *$\delta^{18}O$ vs $\delta^{13}C$ plot of dolomite and calcite cements, and Aptian host carbonates.*

Porosity and permeability

Water porosimetry and constant charge permeameter data from limestone and dolomite samples evidence a very low porosity and permeability. Higher porosity values occur in the host grainstone facies, although this is not associated with a significant increment in permeability. This weak correlation is mostly related to the strong early calcite and dolomite cementation that occurred prior to replacement. Permeability values are slightly higher when measured perpendicular to bedding which is mostly related to the presence of vertical fractures partially open and connected. High degree of fracture connectivity appears in limestones with coarse-sized bioclasts, remaining partially open after replacement, dissolution, and cementation stages. Porosity and permeability values are higher in planar dolomites than in nonplanar dolomites (replacive and recrystallized), indicating the occurrence of tortuous or closed intercrystalline pore-throats (Gregg, 2004).

Conclusions

Field and analytical results indicate that the dolomitization of the Aptian, Benassal Fm took place under shallow burial diagenetic conditions (<1 km), sometime between the final stage of rifting (Albian) and the Late Cretaceous post-rift (Cenomanian to Campanian). Warm dolomitizing fluids, exceeding 60º C were channeled upwards along large-scale faults and subsequently migrated laterally along the top of the Benassal Fm, most probably forced by the Escucha Fm clays. Fluids circulated through fractures and most permeable beds of the Benassal Fm, being the dolomitizing front stopped at the lower porosity host rock facies. The driven mechanism may be related to thermal convection associated with the Late Cretaceous thermal event proposed by Salas et al. (2005).

Late Cretaceous pore-filling dolomite and burial calcite cementation dramatically reduced the porosity of dolomites and limestones, and thus the potential reservoir quality. A significant increase in porosity, and probably in reservoir quality, occurs in the proximity of faults, which is related to Tertiary hydrothermal alteration and later dedolomitzation associated with the Alpine uplift and faulting.

The excellent exposures of the Benicàssim area represent an outcrop to basin scale, new case study for the characterization of fault-associated dolomites. Therefore, the field area could be used an outcrop analog for equivalent oil reservoirs located offshore eastern Spain (Western Mediterranean, Valencia Trough), as well as for other reservoirs in the Middle East and elsewhere.

Acknowledgements

The authors thank ExxonMobil Production Company for providing funding to develop this project.

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