Marine and Petroleum Geology 65 (2015) 83–102

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Fault-controlled and stratabound dolostones in the Late Aptian–earliest Albian Benassal Formation (Maestrat Basin, E Spain): Petrology and geochemistry constrains

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A R T I C L E I N F O

Article history:
Received 5 November 2014
Received in revised form
20 March 2015
Accepted 23 March 2015
Available online 31 March 2015

Keywords:
Dolostone
Fault-controlled
Hydrothermal
Stratabound
Fluid flow
Aptian

A B S T R A C T

Fault-controlled hydrothermal dolomitization of the Late Aptian to earliest Albian Benassal Fm shallow water carbonates resulted in the seismic-scale stratabound dolostone geobodies that characterize the Benicàssim case study (Maestrat Basin, E Spain). Petrological and geochemical data indicate that dolomite cement (DC1) filling intergranular porosity in grain-dominated facies constituted the initial stage of dolomitization. The bulk of the dolostone is formed by a replacive nonplanar-a to planar-s dolomite (RD1) crystal mosaic with very low porosity and characteristic retentive fabric. Neomorphic recrystallization of RD1 to form replacive dolomite RD2 occurred by successive dolomitizing fluid flow. The replacement sequence DC1-RD1-RD2 is characterized by a depletion in the oxygen isotopic composition (mean $\delta^{18}O_{(V\text{-}PDB)}$ values from −6.92, to −8.55, to −9.86‰), which is interpreted to result from progressively higher temperature fluids. Clear dolomite overgrowths (overdolomitization) precipitated during the last stage of replacement. Strontium isotopic composition suggests that the most likely origin of magnesium was Cretaceous seawater-derived brines that were heated and enriched in radiogenic strontium and iron while circulating through the Paleozoic basement and/or Permo-Triassic red beds. Burial curves and analytical data indicate that the replacement took place at burial depths between 500 and 750 m, and by hydrothermal fluids exceeding temperatures of 80 °C. Following the partial dolomitization of the host rock, porosity considerably increased in dolostones by burial corrosion related to the circulation of acidic fluids derived from the emplacement of the Mississippi Valley-Type deposits. Overpressured acidic fluids circulated along faults, fractures and open stylolites. Saddle dolomite and ore-stage calcite cement filled most of the newly created vuggy porosity. Subsequent to MVT mineralization, precipitation of calcite cements resulted from the migration of meteoric-derived fluids during uplift and subaerial exposure. This late calcite cement destroyed most of the dolostone porosity and constitutes the main cause for its present day poor reservoir quality.

1. Introduction

Dolomitized limestone successions have been extensively studied during the last decades favored by the occurrence of important hydrocarbon reservoirs in dolostones. The key parameters controlling the distribution of rock heterogeneities in dolostones, which eventually control reservoir quality, are still poorly

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http://dx.doi.org/10.1016/j.marpetgeo.2015.03.019
0264-8172/

constrained, especially in those resulting from fault-controlled or fault-associated replacement processes (e.g. Duggan et al., 2001; Wilson et al., 2007; Sharp et al., 2010). Structurally-controlled dolostones commonly involve warm subsurface fluids, defining the so-called hydrothermal dolomites (HTD) (Davies and Smith, 2006). These authors synthesized the most important characteristics of HTD in terms of fluid flow of dolomitizing brines along faults and fractures, and highlighted their close association with the genesis and location of Mississippi Valley-Type (MTV) mineral deposits.

Typically, dolostone geobodies adjacent to feeding faults (i.e. fault-related) are irregular in geometry and distributed in patches along the fault trace (e.g., Duggan et al., 2001; Wilson et al., 2007; López-Horgue et al., 2010; Shah et al., 2010; Sharp et al., 2010; Di Cuia et al., 2011; Lapponi et al., 2011; Dewit et al., 2012; Ronchi et al., 2012). Eventually, these bodies extend away from fault zones following suitable layers, resulting in a stratabound dolostone distribution (e.g., Sharp et al., 2010; Lapponi et al., 2011; Dewit et al., 2014). A Christmas tree-like morphology can be recognized when the replacement geometry includes both the patchy and the stratabound end members in an individual dolostone body (e.g., Sharp et al., 2010).

The formation of stratabound dolostones is commonly related to the circulation of dolomitizing fluids along most permeable beds, being grain-dominated carbonate facies typical preferential conduits (e.g., Davies and Smith, 2006; Wilson et al., 2007; Sharp et al., 2010). Lateral flow through permeability pathways like karstic units and/or aquitards are also claimed to facilitated the stratabound geometry (Sharp et al., 2010). More recently, the formation of stratabound HTD dolostones in Matienzo (Basque-Cantabrian Basin, Spain) has been related to mechanical stratigraphy, considering massive limestones beds major barriers to dolomitizing fluids (Dewit et al., 2014). Moreover, late authors claimed that depositional limestone facies played a minor role in the replacement process. Taken into account that mechanical stratigraphy represents the by-product of depositional composition, diagenetic evolution and structure (Laubach et al., 2009), new case studies of stratabound dolostones are of key interest in order to constrain major controls on the dolomitization process.

The Benicàssim outcrop analog (Maestrat Basin, E Spain) constitutes a superb example of fault-controlled hydrothermal dolomitization that resulted in dominant stratabound dolostone geobody morphologies (Gomez-Rivas et al., 2010a, 2010b, 2014; Martín-Martín et al., 2010, 2013; Corbella et al., 2014). In Benicàssim, mud-dominated and highly stylolitized massive limestone beds appear unreplaced within the dolostones bodies, providing an opportunity to constrain the role of diverse parameters in the replacement. In this regard, the Late Aptian depositional facies of the Benicàssim host rock are similar to prolific hydrocarbon reservoirs in the Tethyan realm, and thus may represent a consistent analog for age-equivalent carbonate reservoirs in the Middle East (Martín-Martín et al., 2013). In particular, the Benicàssim dolostones are of significant interest for the study of equivalent fault-controlled partially dolomitized hydrocarbon reservoirs worldwide, as well as those hydrocarbon reservoirs located offshore of eastern Spain (e.g., Clavell and Berastegui, 1991; Lomando et al., 1993).

This paper presents new petrographic and geochemical data of the Lower Cretaceous stratabound dolostones cropping out in the Benicàssim area. In particular, the aims of the study are: (i) to unravel the diagenetic evolution of the carbonate host rock with special emphasis on the replacement process; (ii) to constrain the composition and origin of the dolomitizing fluids; and (iii) to determine the controls on the development of stratabound morphology geobodies.

2. Geological setting

The Benicàssim area is located in the south of the Maestrat Basin (E Spain), which developed during the Late Jurassic–Early Cretaceous rift cycle of the Mesozoic Iberian rift system (Salas and Casas, 1993; Salas et al., 2001) (Fig. 1). The basin was inverted during the Alpine orogeny, and it is thus part of the intraplate Iberian Chain fold-and-thrust belt. Mesozoic syn-rift and contractive Alpine structures were subsequently reactivated and/or overprinted by an extensional phase during the Neogene period (Roca and Guimerà, 1992; Simón, 2004; Gomez-Rivas et al., 2012), which configured the present-day West Mediterranean basin (València Trough).

During the Late Jurassic–Early Cretaceous, the regional NW–SE and NNE–SSW trending extensional faults of the Maestrat Basin bounded several rifted blocks that locally accommodated kilometer-thick Lower Cretaceous syn-rift deposits (Roca et al., 1994; Salas et al., 2001) (Fig. 1). In the study area, the intersection between the NW–SE-trending Campello fault and the NNE–SSW-trending Benicàssim fault resulted in the formation of a semi-graben structure that was filled with ~2100-m-thick syn-rift deposits (Martín-Martín et al., 2013) (Figs. 1 and 2). These authors studied the syn-rift succession and reported one of the thickest Aptian sedimentary records from the western Tethyan realm. Moreover, the Lower Cretaceous syn-rift deposits appear partially dolomitized in close association with the aforementioned seismic-scale regional faults, providing a new case study of fault-controlled hydrothermal dolomitization. These dolostones locally host Mississippi Valley-type (MVT) ore deposits (Figs. 2 and 3).

Dolomitization of the syn-rift succession exclusively affects the Late Aptian to earliest Albian Benassal Fm, which is a ~1500-m-thick carbonate ramp succession formed almost entirely by shallow-water marine deposits (Martín-Martín et al., 2010, 2013) (Figs. 2, 3 and 3). The succession is dominated by orbitolinid foraminifera, coral, and rudist bivalve fauna (Tomás, 2007; Tomás et al., 2007, 2008; Martín-Martín et al., 2013). The platform carbonates are stacked into three transgressive–regressive (T–R) sequences bounded by discontinuity surfaces of regional significance (Bover-Arnal et al., 2009). Rudist-rich lithofacies typically form the top of the T–R sequences, constituting excellent markers that can be followed throughout the study area (Martín-Martín et al., 2013) (Figs. 2 and 3). The top of the Benassal Fm is karstified and fossilized by the tidal clays and sands of the Escucha Fm, which has been interpreted to act as a regional seal for dolomitizing fluids (Martín-Martín et al., 2010).

2.1. Dolostone distribution and geometry

Dolostones dominantly appear in hanging-wall blocks of both the NW–SE and NNE–SSW trending basement faults, forming two main seismic-scale, stratabound and tabular-shaped bodies with an individual maximum thickness of 150-m (Figs. 3 and 4A). These dolostone bodies can be recognized several kilometers away from the fault zones, extending for several thousand square meters over the study area (Fig. 2). Commonly, non-replaced mud-dominated limestones facies appear intercalated between the dolostone geobodies or bounding them (Fig. 4A–C). According to Martín-Martín et al. (2013), these low-porosity facies facilitated the lateral fluid flow along higher porosity and more permeable units, enhancing the stratabound geometry of the dolostones away from the feeding faults. Dolomitization fronts are sharp and wavy and approximately follow the layer boundaries (Fig. 4B–C). However, the dolomitization fronts cross-cut the bedding planes, undulating up and down from centimeters to meters at the outcrop scale (Fig. 4E). These diagenetic fronts frequently correspond to bedding-parallel stylolitic surfaces (Fig. 4F), indicating that stylolites acted as barriers for