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Diagenetic evolution of Tortonian temperate carbonates close to evaporites in the Granada Basin (SE Spain)

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A B S T R A C T

The Granada Basin (SE Spain) is a small basin located in the central part of the Betic Cordillera, structured as such in the late Tortonian and initially connected to the Atlantic Ocean and to the Mediterranean Sea. During the late Tortonian, normal marine conditions prevailed, leading to the deposition of skeletal carbonate sediments on platforms around structural highs. The marine connections were later interrupted, first to the Atlantic Ocean and then to the Mediterranean Sea, and a thick evaporite sequence, marking the transition from marine to continental conditions, was deposited during the latest Tortonian. In this work, the diagenetic evolution of the Tortonian temperate carbonates (TTC), underlying and close to the evaporite bodies, is revealed and discussed. The diagenetic study includes petrographic analyses (conventional petrography, cathodoluminescence, and fluorescence), geochemical analyses (major, minor and trace elements, and $\delta^{13}C$ and $\delta^{18}O$ stable isotopes), and microthermometry of fluid inclusions. In the TTC, marine diagenetic processes such as micritization and fibrous calcite-cement precipitation and mechanical compaction took place during or just after deposition (Eogenesis). An initial burial event (Mesogenesis 1) is characterized by: 1) stabilization of the temperate-water carbonates by freshwater, and 2) porosity occlusion via precipitation of low-Mg bladed and syntaxial/mosaic calcite cements. The TTC were then subaerially exposed (or got close to the surface) during evaporite deposition and underwent pedogenesis, Mg-smectite infiltration, and pyrite formation (Telogenesis 1). Subsequent brine-related diagenetic alterations, such as dolomitization and silica, halite, and sylvite replacements of carbonate grains occurred during a second burial episode (Mesogenesis 2) concomitant with the Messinian lacustrine deposition, this being followed by chemical compaction (stylolite formation). Finally, the area was uplifted and the TTC exhumed. Microstalactitic (dripstone) and fibre/whisker calcite cement precipitation and extensive dissolution relate to this Pliocene–Quaternary late event (Telogenesis 2). In the study case diagenetic history is closely linked to basin evolution, as diagenetic pathways of carbonate rocks were related to major geodynamic events, including basin restriction leading to evaporite deposition, and several episodes of subsidence and uplift. Up to now, only very few diagenetic studies have attempted to demonstrate this correlation between diagenetic history and basin evolution.

1. Introduction

The study of diagenesis bears significant economic interest, given that diagenesis accounts for porosity and permeability evolution (Ehrenberg, 2007). Diagenetic transformations can strongly influence the ability of the sedimentary rocks to host economic quantities of water, gas, oil, and minerals (Ehrenberg and Nadeau, 2005; Rossi, 2010). In this respect, it is essential to ascertain the chemical conditions, nature, and timing of the diagenetic processes altering sediment and sedimentary-rock properties.

Focusing on the diagenetic evolution of carbonate rocks underlying evaporites, the present work examines the impact of brine circulation and associated diagenetic transformations on potential, carbonate-rock reservoirs close to evaporites, calibrating their relative importance with respect to other, non-evaporite-linked diagenetic transformations that these same rocks could have undergone. The relevance of this study relates to the considerable interest for the exploration and production of pre-salt reservoirs, which represent some of the main oil and gas sources discovered over the last decade. For example, the “Pre-Salt Carbonates of the South Atlantic” have emerged as among the most prolific petroleum systems in the world, providing many billions of barrels of oil reserves (Beasley et al., 2010; Verwer and Lukasik, 2014).

The Granada Basin (SE Spain), selected for this study, is located in the central part of the Betic Cordillera. This basin was initially marine

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and was isolated from the sea during the latest Tortonian. As a result, a thick (up to 500 m thick) salt (halite) sequence accumulated at its centre (García-Veigas et al., 2013). In the Granada Basin, post-salt sediment burial is not deep enough to reach the critical values needed to induce halokinesis salt movements (Hudec and Jackson, 2007). This young sedimentary basin thus provides the suitable context to check the effects of early diagenetic processes in carbonates underlying evaporites before a strong burial event occurs, such as the one undergone by the South Atlantic carbonate reservoirs. The structural and sedimentological framework of the Granada Basin is well constrained (see below), but no diagenetic studies have been conducted until now in any of its deposits.

The Tortonian temperate-carbonate (TTC) sediments, deposited prior to the evaporites in the Granada Basin, constitute the target for this work. Temperate-water carbonates (Lees and Buller, 1972), also known as cool-water (Brookfield, 1988) or non-tropical carbonates (Nelson, 1988), are common shallow-water marine deposits in the Neogene basins of southern Spain. In the Mediterranean-linked basins of the Betic Cordillera (sensu Braga et al., 2003), such as the Granada Basin, they developed at different times during the Neogene and alternate with tropical carbonates (Martín et al., 2010). In the Atlantic-linked basins (Guadalquivir and Ronda basins) their presence was overwhelming in siliciclastic-free, shallow-water platform areas all along the Neogene (Baceta and Pendón, 1999; Gläser and Betzler, 2002; Martín et al., 2009; Braga et al., 2010; Aguirre et al., 2015).

2. Geological setting

The Granada Basin is a small (50 × 50 km) Neogene intramontane basin located in the central sector of the Betic Cordillera (Fig. 1), at the contact between the two major domains, i.e. the Internal Zones (cropping out at Sierra Tejeda, Sierra de la Pera and Sierra Nevada), and the External Zones (cropping out at Sierra Gorda and Sierra Arana; Fig. 2). Its Neogene–Quaternary infilling (Fig. 3) unconformably overlies an irregular, fault-controlled, basement palaeorelief surface (Morales et al., 1990). The main fault systems have an EW orientation (Sanz de Galdeano, 2008). Secondary faults, trending NW–SE, cut and displace the major EW faults and define the principal subsiding areas of the central and eastern part of the basin (Rodríguez-Fernández and Sanz de Galdeano, 2006).

The current Granada Basin depression formed in the late Tortonian (at around 8.3 Ma: Braga et al., 2003; Rodríguez-Fernández and Sanz de Galdeano, 2006; Corbí et al., 2012). The sedimentary infilling extends from the upper Tortonian to the Quaternary. Older continental and marine, lower–middle Miocene sediments (Braga et al., 1996), cropping out at the eastern and southern margins of the depression (Figs. 2, 3), were deposited in a former basin with a completely different structure (Braga et al., 2003).

During the late Tortonian (8.3 to 7.3 Ma) major tectonic activity took place in the north-eastern and eastern highland edges of the basin (Sierra Arana and Sierra Nevada, Figs. 2, 3), leading to the deposition of significant quantities of terrigenous sediments at the base of the uplifted areas (Braga et al., 1990, 2003; Martín and Braga, 1997). Marine conditions prevailed and skeletal carbonate sediments accumulated in siliciclastic-free areas on platforms all around the margins of the basin. Temperate-water carbonates (Puga-Bernabéu et al., 2008) formed first, between 8.3 and 7.8 Ma (Corbí et al., 2012), followed by tropical, coral-reef carbonates (Braga et al., 1990), between 7.8 and 7.3 Ma (Corbí et al., 2012). The Tortonian temperate carbonates (TTC) have been studied in detail at one locality (Alhama de Granada) by Puga-Bernabéu et al. (2008). They consist of carbonates (calcarenites and calcirudites), and mixed siliciclastic–carbonate sediments, containing abundant fragments of bryozoans, bivalves, and coralline algae, and smaller amounts of echinoids, benthic foraminifers and brachiopods.

During the late Tortonian the Granada Basin was a marine embayment initially connected to the Atlantic Ocean to the northwest (Martín et al., 2014) and to the Mediterranean Sea to the south and west (Braga et al., 1990). In the course of the late Tortonian, these marine connections were interrupted first to the Atlantic Ocean and then to the Mediterranean Sea (Martín et al., 1984, 2014; Braga et al., 1990, 2003). As a result the basin desiccated (Martín et al., 1984) in the latest Tortonian (7.3 to 7.2 Ma, Corbí et al., 2012). An evaporitic basin developed with stromatolites at the margin (Martín et al., 1984; García-Veigas et al., 2015), selenite gypsum accumulating in its shallow-water areas (Dabrio et al., 1982) and halite in its centre (García-Veigas et al., 2013). The resulting evaporitic unit, the "Lower Evaporite Unit" sensu Dabrio et al. (1982), marks the marine-to-continental transition in basin evolution (Martín et al., 1984).

During the Messinian, the uplift of the Granada Basin continued and it was filled by continental alluvial-fan, and fluviatile and lacustrine deposits including carbonates and evaporites (the "Upper Evaporite Unit"

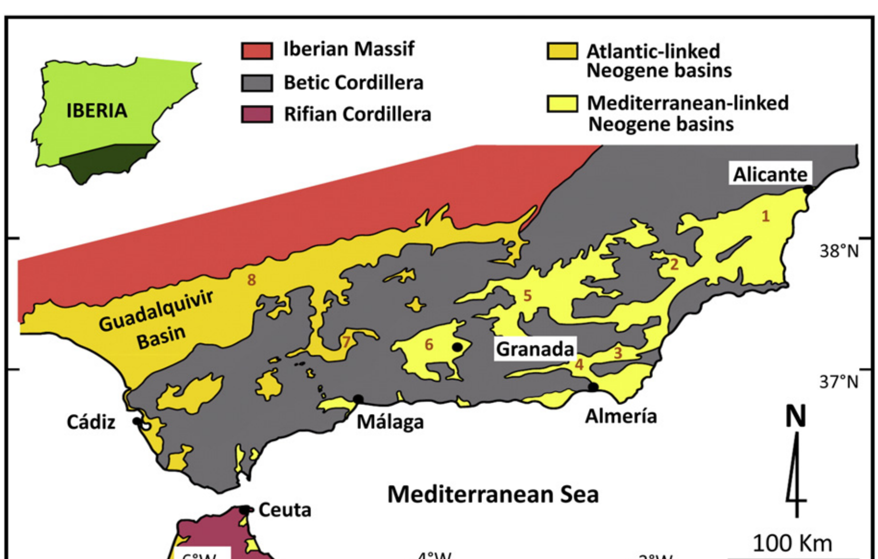

Fig. 1. Neogene sedimentary basins of the Betic Cordillera, Spain (modified from Braga et al., 2003). 1): Fortuna Basin, 2): Lorca Basin, 3): Sorbas Basin, 4): Tabernas Basin, 5): Guadix-Baza Basin, 6): Granada Basin, 7): Ronda Basin, and 8): Guadalquivir Basin.