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Impact of stylolitization on diagenesis of a Lower Cretaceous carbonate reservoir from a giant oilfield, Abu Dhabi, United Arab Emirates

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ABSTRACT

Bed-parallel stylolites are a widespread diagenetic feature in Lower Cretaceous limestone reservoirs, Abu Dhabi, United Arab Emirates (UAE). Diagenetic calcite, dolomite, kaolin and small amounts of pyrite, fluorite, anhydrite and sphalerite occur along and in the vicinity of the stylolites. Petrographic observations, negative $\delta^{18}O_{VPDB}$, fluid inclusion microthermometry, and enrichment in ^{87}Sr suggest that these cements have precipitated from hot basinal brines, which migrated along the stylolites and genetically related microfractures (tension gashes). Fluid migration was presumably related to lateral tectonic compression events related to the foreland basin formation. The low solubility of Al^{3+} in formation waters suggests that kaolin precipitation was linked to derivation of organic acids during organic matter maturation, probably in siliciclastic source rocks. The mass released from stylolitization was presumably re-precipitated as macro- and microcrystalline calcite cement in the host limestones. The flanks of the oilfield (water zone) display more frequent presence and higher amplitude of stylolites, lower porosity and permeability, higher homogenization temperatures and more radiogenic composition of carbonates compared to the crest (oil zone). This indicates that oil emplacement retards diagenesis. This study demonstrates that stylolitization plays a crucial role in fluid flow and diagenesis of carbonate reservoirs during basin evolution.

1. Introduction

Stylolitization is a widespread diagenetic process in oil and gas carbonate reservoirs around the world, including Abu Dhabi, United Arab Emirates (Oswald et al., 1995; Alsharhan and Sadd, 2000; Morad et al., 2012). Stylolitization is considered to be influenced by limestone texture, facies and mineralogy, and affects reservoir porosity and permeability (Railsback, 1993; Andrews and Railsback, 1997; Baron and Parnell, 2007; Vandeginste and John, 2013). The presence of diagenetic minerals along stylolites and seams has led authors to conclude that stylolitization and related fracturing are associated with fluid flow (Braithwaite, 1989; Neilson et al., 1998; Smith, 2000; Evans and Elmore, 2006; Baron and Parnell, 2007; Neilson and Oxtoby, 2008; Heap et al., 2014; Khalifa and Morad, 2015). Moreover, it has been argued that fluid flow along stylolites influences petroleum generation (Leythaeuser et al., 1995) and migration (Baron and Parnell, 2007).

The development of stylolites and precipitation of cement along them are commonly thought to be slowed by oil emplacement, and hence contributing to the diagenetic difference between oil and water zones (Oswald et al., 1995; Neilson et al., 1998; Melville et al., 2004). Cements along stylolites have been related to mass derived from dissolution of the host limestones or to externally derived basinal brines (Neilson and Oxtoby, 2008).

Despite these observations and interpretations, the characteristics and timing of fluid migration along stylolites are still poorly constrained in the literature.

The principal oil reserves in Abu Dhabi are present in stylolitized limestones of Lower Cretaceous age, being entrapped in enormous anticlinal structures at 2–4 km depth (Alsharhan, 1989; Strohmenger et al.,

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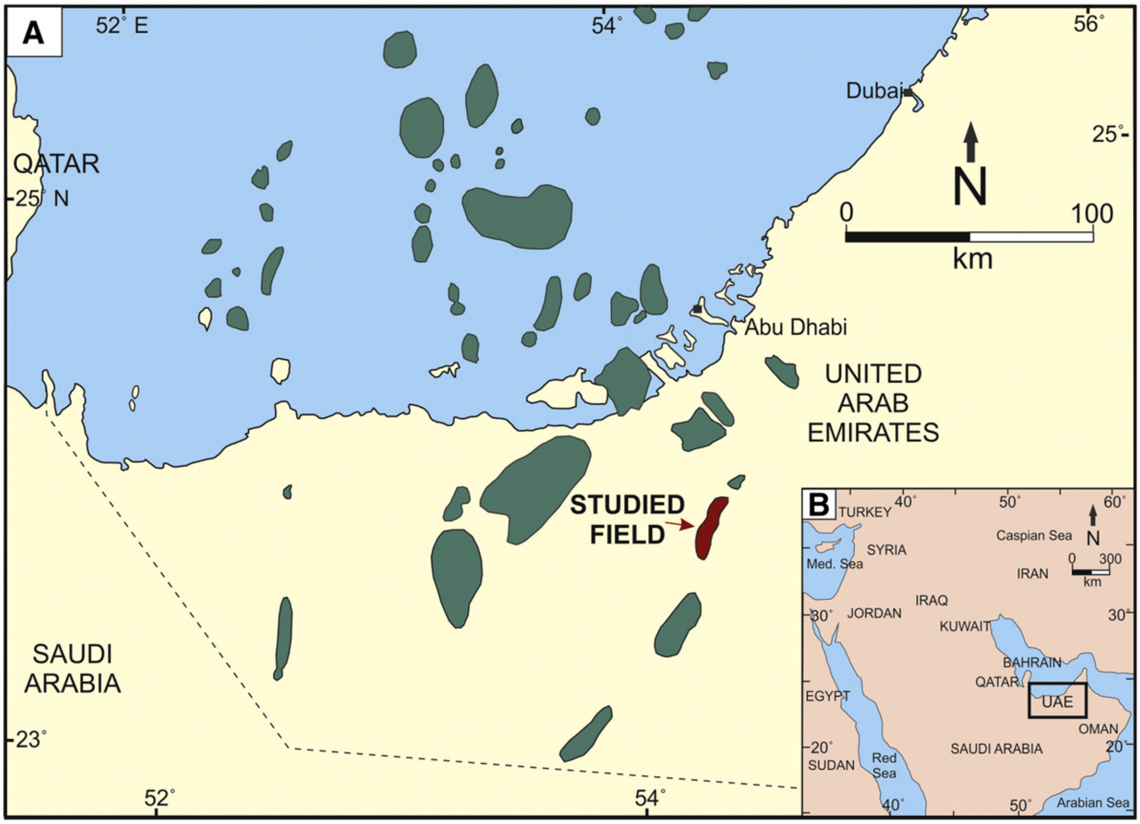

Fig. 1. (A) Regional map indicating the main oilfields, onshore and offshore Abu Dhabi, UAE. The oilfield investigated in this research (red-filled) is indicated with an arrow. **(B)** Small scale location map.

2006) (Fig. 1). The objectives of this integrated petrographical, geochemical and fluid inclusion study are to constrain: (1) the characteristics and timing of fluid migration along stylolites, and (2) the impact of these fluids on the diagenetic evolution of the host limestones in the crest (oil zone) and flanks (water zone) of the anticline.

2. Geological setting

The UAE is situated in the southeastern part of the Arabian Plate, within the interior platform of the Arabian shelf, bounded to the west by the Qatar arch and to the east and northeast by the foreland basin and adjacent fold and thrust belt of Oman (Alsharhan and Salah, 1997). Two orogenic events have affected the region. The first event (Late Cretaceous) is related to the obduction of Oman Ophiolites and adjacent carbonate succession onto the eastern margin of the Arabian platform (Searle, 1985; Robertson and Searle, 1990; Johnson et al., 2005). The second event is the Zagros Orogeny, which resulted from the closure of the Neo-Tethys Ocean between the Arabian and Eurasian plates (e.g. Stampfli and Borel, 2002; Agard et al., 2005; Hafkenscheid et al., 2006). The initial collision between these plates was suggested to be during Late Eocene to Oligocene (e.g. Jolivet and Faccenna, 2000; Agard et al., 2005; Agard et al., 2011). The Zagros Orogeny, which extends from the Turkish–Iranian border to the NW to the Makran area in the SE where oceanic subduction, is still active (Blanc et al., 2003; Ellouz-Zimmermann et al., 2007).

The structure of the studied onshore giant oilfield (Fig. 2) is a faulted and fractured anticline, having a length of approximately 25 km and a width of 7.5 km. This anticline resulted from compression provoked by convergent tectonics at the Arabian Plate boundary in Oman (Sharland et al., 2001), particularly in relation to the so-called Masira event (late Maastrichtian/Paleocene) (Johnson et al., 2005). This series of events resulted also in the development of foreland basin and initiation of hydrocarbon maturation and migration (Oswald et al., 1995; Cox et al., 2010). Oil charging into the reservoir occurred dominantly during the late Cretaceous to Eocene (Taher, 1997; Vahrenkamp et al., 2014).

During the Barremian and early Aptian, the southeastern Arabian Plate was characterized by the development of a broad carbonate ramp, where the Kharaib Formation of the Thamama Group was deposited (Fig. 3). This event was followed by the formation of an intrashelf basin, surrounded by a carbonate platform (Shuaiba Formation and Bab Member, Aptian) (Van Buchem et al., 2002 and 2010; Hillgärtner et al., 2003; Vahrenkamp et al., 2014) (Fig. 3).

This study concentrates on the Upper Kharaib carbonate reservoir (UKR), which comprises mainly packstones, grainstones and wackestones. The upper part of the UKR, is coarser grained (rudist-rich grainstones and packstones) than the lower part (Orbitolinid-rich wackestones). A third-order maximum flooding surface occurs between these two facies packages (Van Buchem et al., 2002; Strohmenger et al., 2006). The UKR is commonly embedded by two so-called dense zones (called upper dense zone (UDZ) and middle dense zone (MDZ)), which comprise mainly clay-rich mudstones, wackestones and locally packstones having very low porosity and permeability (Alsharhan and Sadd, 2000). The limestones constituting the dense zones have been deposited in lagoonal inner ramp and deep subtidal lower ramp. A third-order sequence boundary is located at the base of the UDZ (Strohmenger et al., 2006) (Fig. 3). No evidence of syn-Thamama structural development has been reported within the study area and no important tectonic events happened until the Turonian (unconformity) along the eastern Arabian shelf (Oswald et al., 1995).

The main possible source rocks include the argillaceous limestones of the Diyab Formation (Oxfordian–Kimmeridgian) (Loutfi and El Beshlawy, 1986; Gumati, 1993; Alsharhan and Scott, 2000) and/or the