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Impact of depositional facies on the distribution of diagenetic alterations in the Devonian shoreface sandstone reservoirs, Southern Ghadamis Basin, Libya

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ABSTRACT

The middle Devonian, shoreface quartz arenites (present-day burial depths 2833-2786 m) are important oil and gas reservoirs in the Ghadamis Basin, western Libya. This integrated petrographic and geochemical study aims to unravel the impact of depositional facies on distribution of diagenetic alterations and, consequently, related reservoir quality and heterogeneity of the sandstones. Eogenetic alterations include the formation of kaolinite, pseudomatrix, and pyrite. The mesogenetic alterations include cementation by quartz overgrowths, Fe-dolomite/ankerite, and illite, transformation of kaolinite to dickite, illitization of smectite, intergranular quartz dissolution, and stylolitization, and albitization of feldspar. The higher energy of deposition of the coarser-grained upper shoreface sandstones combined with less extensive chemical compaction and smaller amounts of quartz overgrowths account for their better primary reservoir quality compared to the finer-grained, middle-lower shoreface sandstones. The formation of kaolin in the upper and middle shoreface sandstones is attributed to a greater flux of meteoric water. More abundant quartz overgrowths in the middle and lower shoreface is attributed to a greater extent of stylolitization, which was promoted by more abundant illitic clays. This study demonstrated that linking the distribution of diagenetic alterations to depositional facies of shoreface sandstones leads to a better understanding of the impact of these alterations on the spatial and temporal variation in quality and heterogeneity of the reservoirs.

1. Introduction

Shoreface sandstones are important hydrocarbon reservoirs in basins around the world (Ambrose et al., 1998). Improving hydrocarbon recovery requires thorough understanding of the depositional facies, sequence stratigraphy, and diagenesis of such sandstone reservoirs (Emery and Myers, 1996; Posamentier and Allen, 1999; Morad et al., 2000, 2010; Lima and De Ros, 2002; Al-Ramadan et al., 2005). Depositional facies, which control the primary porosity and permeability, pore water chemistry, and sand-body geometry, exert substantial impact on the distribution of eogenetic alterations (Hartmann and Beaumount, 1999; Morad et al., 2000, 2010; Salem et al., 2000; Stonecipher, 2000; Luo et al., 2009; Brenner et al., 2010; Odigi, 2011). Mesogenetic alterations are controlled mainly by burial-thermal history, formation-water chemistry, and distribution patterns of eogenetic alterations (Burley et al., 1985; Morad et al., 2000, 2010, 2012; Khalifa and Gasparrini, 2014). There are relatively few studies integrating diagenesis into depositional facies, which should provide a better understanding of the spatial and temporal distribution of reservoir quality in shoreface sandstones (Al-Ramadan et al., 2005, 2012a, 2012b).

The goals of this study are to constrain the impact of depositional facies on reservoir quality and diagenetic evolution of the Devonian shoreface sandstones of the southern Ghadamis Basin, western Libya (Fig. 1). The study demonstrates the importance of facies-controlled diagenesis, particularly the distribution of clay minerals and quartz overgrowths, on reservoir quality distribution of quartzose shoreface sandstones.

2. Geological setting

The Ghadamis Basin is a large intracratonic sag basin developed on the passive northern margin of Gondwana (Sutcliffe et al., 2000; Hallett, 2002). The basin covers an area of 350,000 km^2 with the depocenter located west of Tihemboka Uplift in Algeria and Tunisia (Fig. 1). The basin is bounded by the Amguid El-Biod Uplift to the west, Hoggar Massif and Gargaf Arch to the south, Nafusah Uplift to the north, and to the east the basin wedges out beneath the western part of the Sirt Basin (Baudet, 1988; El-Arnauti and Shelmani, 1988; Echikh, 1998) (Fig. 1A, B). The basin is characterized by complex stratigraphic thickness variations as a result of several major tectonic (uplift,

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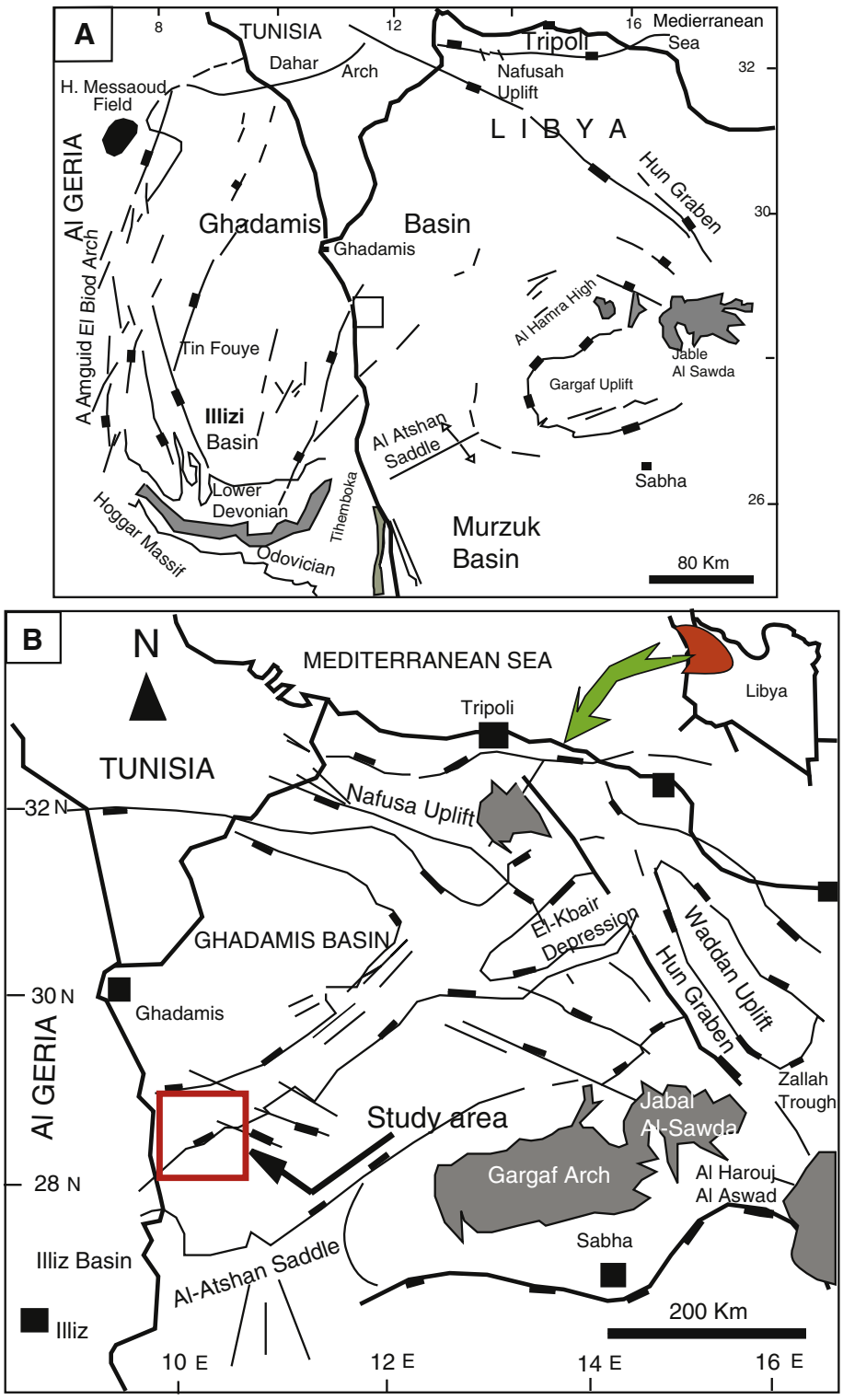

Fig. 1. Geological map showing: (A) location and boundaries of the Ghadamis Basin western Libya. The gray areas represent the volcanic rocks of the Al-Haroj Al-Aswda in central Libya, and the Hoggar Massif in SE Algeria. (B) The eastern part of the Ghadamis Basin indicating the study area (modified after Echikh, 1998; Elruemi, 2003). The red area represents the Ghadamis Basin in NW Libya, whereas the green arrow indicates the eastern part of the Ghadames Basin.

erosion, folding, and faulting) events, including the Caledonian, Hercynian, and Austrian phases (Echikh, 1998). Tectonic evolution of the basin occurred in three major phases: (i) subsidence through reactivation of Pan-African fault systems of a subsiding Paleozoic Basin, (ii) uplift and erosion of much of the Paleozoic section during the Hercynian Orogeny, and (iii) a north-west tilting and superimposition of the Mesozoic extensional basin (Echikh, 1998).

3. Devonian stratigraphy

The stratigraphic column of the Ghadamis Basin shows that Devonian sandstones of the Tadrart, Ouan Kasa, Aouinet Ouenine, and Tahara formations unconformably overlie the Tanezzuft Shale (early Silurian) and Acacus sandstones (late Silurian) (Massa and Moreau-Benoit, 1976; Belhaj, 1996; Underdown, et al., 2007) (Fig. 2). The alternating