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Research paper

Reservoir heterogeneity and quality of Khuff carbonates in outcrops of central Saudi Arabia

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ABSTRACT

The Khuff carbonates host several main gas reservoirs in the Middle East. These reservoirs are known for their heterogeneity, both of sub-seismic scale and beyond the interwell spacing. To get a better insight in these reservoirs, the heterogeneity of the Upper Khartam Member, placed in a high-frequency sequence stratigraphic framework, was studied with a lateral resolution between logged sections of 5 m. The sedimentology and sequence stratigraphy of four outcrop localities were studied, and approximately 600 samples were collected for petrographic, porosity and permeability analyses.

Seventeen lithofacies types were recognised and six major diagenetic processes could be differentiated in the studied outcrops. Dissolution is likely the result of intensive circulation of meteoric water undersaturated with respect to calcite. Significantly, cementation has blocked most of the original intergranular porosity. Pore lining detrital clay severely impacted reservoir permeability and complicated the pore geometry. Dolomitization is associated with the upper Khuff–Sudair boundary, and is likely the result of influx of water highly saturated with Mg^{+2} that developed during the deposition of the Sudair evaporites. Finally, stylolites are to a major extend controlled by lithofacies and geobody configuration. Ten porosity types could be namely: intergranular, intragranular, shelter, dissolution-enlarged, moldic, vuggy, micro-porosity, and porosity in relation to dolomite–dedolomite, dolomite-leaching, and fracture development. Overall intertidal creeks are characterized by a complex and heterogeneous pore geometry if compared to the intertidal channels, and this can be attributed to the geobody architecture, with intertidal creeks being composed of dense and small tidal bodies (1 m in length and 20 cm in thickness), while intertidal channels are composed of thick amalgamations of intertidal channels (5 m by 50 cm). Most critically, the horizontal reservoir quality was influenced differentially by diagenesis, which resulted in a lateral segmentation of single bodies into different, hydraulic units. The differential mold-filling calcite cements have significantly reduced porosity and permeability. Generally, mineral content has little impact on the reservoir quality, although clay minerals played a central role in lining the pore space and affecting permeability. Finally, horizontal reservoir heterogeneity seems to have been controlled by fractures and stylolites which respectively acted as conduits to and barriers for vertical fluid flow and, hence, controlled the differential cementation and dissolution processes.

1. Introduction

The key question when addressing reserve estimations and propose improved productivity is to quantitatively assess reservoir heterogeneity. This includes the identification of geobody architecture and porosity and permeability of the reservoir building blocks at scales ranging from pore-geometry to inter-well spacing. Obviously, this range cannot be covered by subsurface data alone. Generally, reservoir geobody architecture from outcrop analogues provide valuable insight into ancient sedimentary processes and products. (Alnazghah et al., 2013; Grammer et al., 2004; Haase and Aigner, 2013; Jung and Aigner, 2012; Koehrer et al., 2012, 2011, 2010; Pringle et al., 2006; Smith and Read, 1999; Walz et al., 2013; Zeller et al., 2011). In addition to processes affecting sedimentary rock composition such as biological evolution, sea-level fluctuation, paleo-position, and tectonic overprinting, diagenetic alteration is one of the critical factors on reservoir

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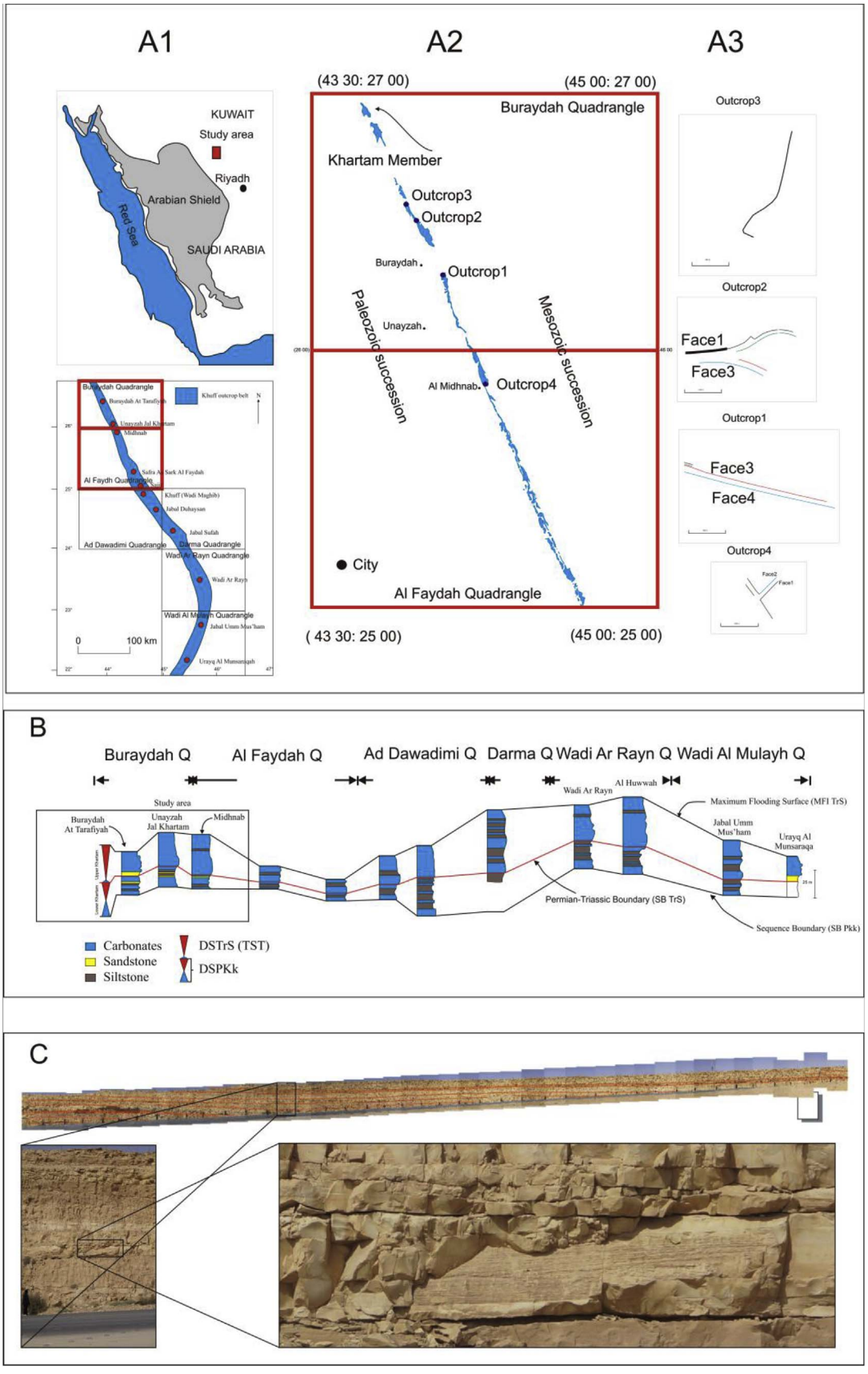

Fig. 1. Location maps and cross-sections. A1, A2, and A3) Khuff Formation outcrop in central Saudi Arabia, with the Khartam Member belt in the Buraydah and Al Faydah quadrangles, and the studied outcrop sections respectively. Three outcrops are located in the Buraydah quadrangle while outcrop 4 is located in the Al Faydah quadrangle (modified after Manivit et al., 1985b; Vaslet et al., 1985, 2005), (B) regional correlation and variations in facies and stratal thicknesses of the Upper Khartam Member (modified after Vaslet et al., 2005), (C) illustration of one of the studied road-cuts (outcrop 2) (note the location of the photomosaic in upper photograph (bold black) and the different zooms (lower photogrphs in C; for scale see the man in the bottom left corner).