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Factors shaping reservoir architecture in the Jurassic Arab carbonates: A case from the Persian gulf

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ABSTRACT

The Upper Jurassic Arab Formation of the Ferdowsi Oil Field represents deposition in a high-energy sub-equatorial carbonate ramp. Prevailing arid climate and sea-level fluctuations resulted in four shallowing-up 3rd order sequences, starting with porous and permeable reservoir rocks and ending with low permeable evaporites (local sealing units), causing vertical compartmentalization in the field. Repeated successions of shoal, lagoon, and peritidal facies with shoaling-upward cycles in various orders formed variable reservoir zones. Reservoir quality was primarily controlled by depositional setting, but post-depositional processes were also important in enhancing/creating porosity, especially in the lagoonal facies. Marine cementation by development of rigid framework resulted in the preservation of primary poroperms values even after burial. In addition, evaporite capping led to further primary reservoir preservations by creation of a hydro-pressurized system.

Six petrophysical groups (PGs) are distinguished in the studied interval by considering primary and secondary controls on pore type and size distribution. Accordingly, high-quality PGs are distributed in the lower parts of the sequences, and the least permeable PGs in the upper parts. The spatial distribution of each PG is justified by its position within the sequence stratigraphic framework of the field and thus petrophysical and general reservoir architecture of the field could be established. Consistent with this reservoir rock classification, the Arab B and A Members have higher reservoir quality than the underlying Arab C and D Members in this field. Accordingly, the general reservoir architecture in this field is mainly shaped by arrangements and features of depositional sequences.

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1. Introduction

Reservoir characterization or spatial distribution of petrophysical properties (Lucia, 2007) is undertaken by both geologists and reservoir engineers to illustrate the general reservoir architecture or internal reservoir geometry. Classification of reservoir rocks using petrophysical characteristics (rock typing) is a process, by which different reservoir zones or three dimensional reservoir bodies can be differentiated based on their individual petrophysical properties such as porosity, permeability or saturation (Archie, 1952). In other words, a rock type is an individual body of rocks, which inherit specific petrophysical properties from different primary (depositional) and secondary (post-depositional) processes. Accordingly, the best schemes for rock typing are those taking into account the rock fabrics, namely the result of the interaction of the primary and secondary processes (Lucia, 2007).

The Upper Jurassic Arab Formation contains the most prolific reservoir rocks of the world (Bates, 1973; Beydoun, 1988, 1991, 1998). This formation is encountered in many parts of the Arabian Plate, mostly occurring as reservoirs in the Persian Gulf, Abu Dhabi, offshore U.A.E., Saudi Arabia, Bahrain, and Qatar (see Alsharhan and Kendall, 1986; Alsharhan and Nairn, 1997 for more information). Its type section (127.5 m) has been selected in the well Dammam-7 of the Dammam Field, in eastern Saudi Arabia (Steineke et al., 1958; Powers, 1968). The first lithostratigraphic description of the unit by Steineke et al. (1958) led to its subdivision into four members, which are currently applicable over Arabia and neighboring countries. Accordingly, it comprises the Arab D, C, B and A members, from base to top, each containing a shallowing-upward cycle of carbonate to evaporite (Fig. 1a, b). The uppermost evaporite unit, overlying carbonates of the Arab A Member, has been named as the Hith Formation (Powers, 1962, 1968), which makes the principal regional seal for the Jurassic reservoirs in the south and southwest of the Persian Gulf (Murris, 1980, 1981).

Although this unit has been studied for many years (e.g. Steineke et al., 1958; Powers, 1962; Wilson, 1985; Beydoun, 1988; Mitchell et al., 1988; Alsharhan and Whittle, 1995; Meyer et al., 1996; Al-Husseini,

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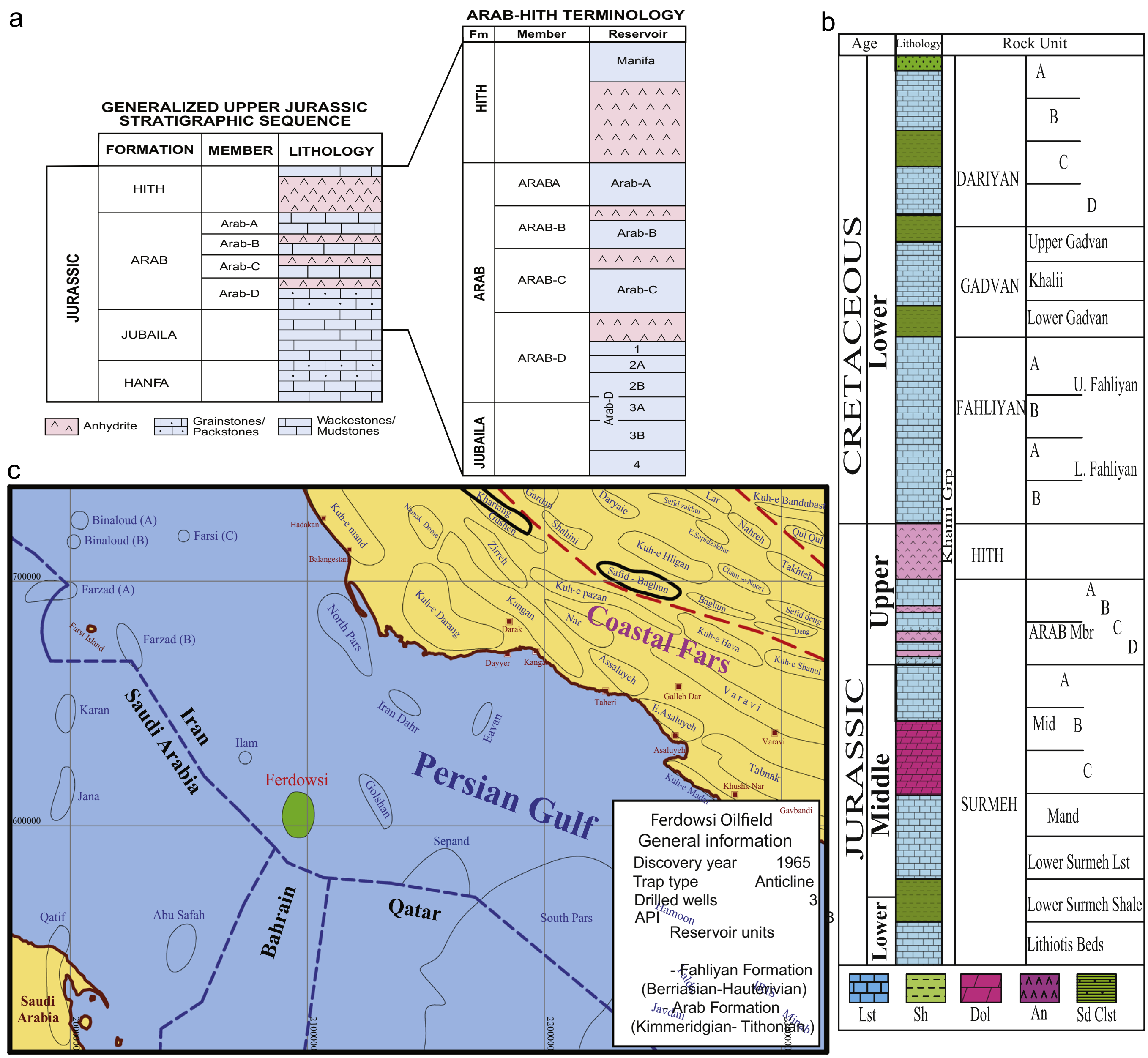

Fig. 1. (a) Schematic display of the Upper Jurassic stratigraphy used in eastern Saudi Arabia (from Cantrell et al., 2001). (b) Stratigraphic position of the Arab Formation in the Ferdowsi Oil Field. The formation here is regarded as a member of the Surmeh Formation. (c) Location map of the Ferdowsi Field.

1997; Lucia et al., 2001; Al-Saad and Sadooni, 2001; Cantrell et al., 2004; Cantrell, 2006; Lindsay et al., 2006; Eltom et al., 2013), no substantial published data are available from its Iranian counterpart.

In this study, the Arab Formation is examined in three exploration wells, located within the Ferdowsi heavy oil field, offshore Iran (Fig. 1c). The main objectives of the study are: (1) to reconstruct depositional environment of the Arab Formation, (2) to clarify the role of depositional and post-depositional processes on general reservoir quality and architecture, (3) to present a reservoir rock classification scheme, and (4) to establish a framework for field-scale correlation of rock types.

2. Geologic setting

After fragmentation of eastern Gondwana, triggering Neothetys Ocean creation, and during early to late Jurassic, a transgressive carbonate platform was established on the passive margin of the Arabian Plate, in which some intrashelf basins (e.g. Lurestan, western Abu Dhabi, eastern Qatar, Gotnia, Rub'Al Khali; Ghawar, Dukhan) were created due to sea-floor differential movements (Murris, 1980; Alsharhan and Kendall, 1986; Sharland, 2001; Ziegler, 2001; Alsharhan and Nairn, 1997). Following minor sea-level fluctuations, which continued over the Jurassic transgressive system (e.g. Murris, 1980), this platform and the associated basins hosted the most important petroleum systems of the world (Alsharhan and Nairn, 1997). Particularly, in the late Jurassic, sedimentation kept pace and sometimes exceeded accommodation space, resulting in alternative successions of carbonate and evaporite (Alsharhan and Nairn, 1997). On the other hand, euxinic condition prevailed across the intrashelf basins, providing sites for source rock accumulation (Murris, 1980; Ayres et al., 1982; Alsharhan and Kendall, 1986; Droste, 1990; Carrigan et al., 1995). Consequently, the combination of tectonic movements and sea-level fluctuations associated with the arid climatic conditions (Handford et al., 2002; Cantrell, 2006) led to the best trilogy of

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