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Research paper

Microfacies, depositional environment and diagenetic evolution controls on the reservoir quality of the Permian Upper Dalan Formation, Kish Gas Field, Zagros Basin

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ABSTRACT

The Upper Permian Upper Dalan Formation contains one of the largest gas reservoirs in the world. The formation consists of carbonates with some evaporite intercalations that developed on a gently sloping homoclinal carbonate ramp facing the Late Permian Paleo-Tethys Ocean. This study focuses on the Kish Gas Field (Zagros offshore basin situated between Iran and Qatar), and is based on a 222-m-thick continuous core. Based on the integration of core- and wireline-log data coupled with petrographic analyses of 580 thin sections, three major depositional environments (facies belts) with 11 carbonate microfacies are identified. These include (1) sabkha to tidal flat (laminated to massive anhydrite, dolomudstone with anhydrite nodules, dolomudstone, and intraclastic dolowackestone), (2) lagoon and leeward shoals (bioclastic wackestone/dolowackestone to packstone, and peloid dolopackstone and peloid–bioclastic dolopackstone), and (3) mobile (windward) sand shoal (ooid–peloid dolograinstone, ooid dolograinstone, ooid–intraclast dolograinstone, ooid–bioclast dolograinstone–packstone, and coarse bioclast–intraclast dolograinstone). Diagenetic evolution of the Upper Dalan Formation is associated with evaporative marine, shallow-water normal-marine, meteoric, and burial diagenetic environments. Common diagenetic effects include dolomite and calcite cementation, mechanical and chemical compaction, dissolution, dolomitization, and evaporative (anhydrite) mineralization.

Reservoir quality is strongly affected by variations in the original rock fabrics and subsequent diagenetic alterations. The most common pore types include interparticle, moldic, and connected vug (fracture and cavernous). The interparticle porosity–permeability relationship for the studied facies suggests that the reservoir quality is not affected by different crystal sizes and most samples plot in the low porosity and low to high permeability field, or display Lucia class 1 or 2 petrophysical relationships. The study shows that the pervasive pore-filling anhydrite mineralization lead to a significant decrease in porosity and permeability; poikilotopic anhydrite cement reduced matrix porosity, but the pore size was less affected.

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1. Introduction

The Persian Gulf Basin is considered as one of the most prolific hydrocarbon basins in the world. It consists of a multi-stage petroleum system composed of major reservoir units spanning the Paleozoic to Cenozoic (Sadooni and Alsharhan, 2004). In the Late Paleozoic system, the Upper Dalan Formation constitutes one of the most important gas reservoir units due to existence of a thick dolomitized carbonate sequence with appropriate reservoir properties and a few evaporite intervals that act as hydrocarbon (gas) seals (Insalaco et al., 2006) (Fig. 1). The formation contains more than 50% of the current gas reserves discovered in the

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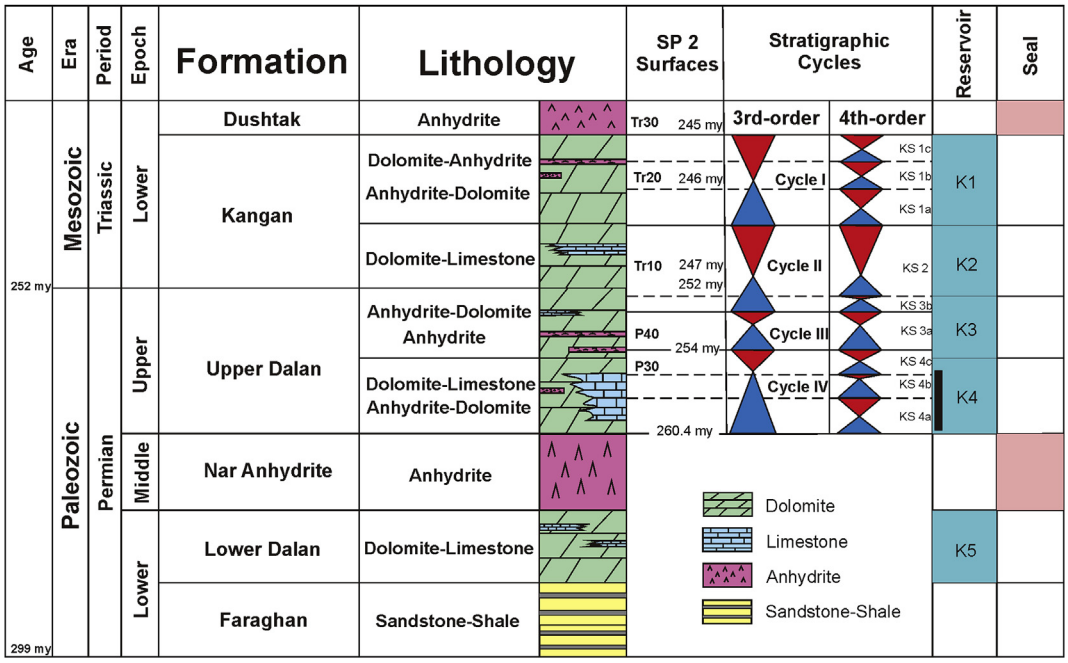

Figure 1. Generalized Upper Permian–Lower Triassic chronostratigraphy, lithostratigraphy, and sequence stratigraphic framework of the Zagros Basin (modified from Sharland et al., 2001; Insalaco et al., 2006). The studied Upper Dalan Formation comprises a major reservoir of the Zagros basin (K4).

Persian Gulf Basin (Sadooni and Alsharhan, 2004), as well as some of the most important upper Paleozoic gas reserves in the world. The Upper Dalan Formation is equivalent to the subsurface Upper Khuff Formation of the Arabian Peninsula (Saudi Arabia, Kuwait and Oman; Ehrenberg et al., 2007), the subsurface Chia Zairi Formation in Iraq (Aqrawi, 1998), the surface Bih and Hagil Formations of the eastern United Arab Emirates (Strohmenger et al., 2002; Maurer et al., 2009), and the surface Saiq and Mahil Formations of Oman (Koehrer et al., 2010, 2012). However, unlike the well-studied Khuff Formation (El-Bishlawy, 1985; Alsharhan and Kendall, 1986; Al-Jallal, 1987, 1994, 1995; Alsharhan, 1993; Al-Aswad, 1997), the Upper Dalan Formation has received much less attention, both in the subsurface and outcrop-based studies. Szabo and Kheradpir (1978) carried out the first sedimentological and stratigraphical study in the Zagros area in which they established both well- and surface reference sections for the Permian–Triassic of the Zagros Basin, and briefly described the Upper Dalan Formation. Following this pioneer work, Insalaco et al. (2006) published a comprehensive study on the Upper Permian to Lower Triassic reservoirs in Iran, addressing also the stratigraphy and biostratigraphy of the Upper Dalan Formation by using both surface and subsurface data from the South Pars field. Based on the subsurface data from South Pars, North Pars, and Khu-I-Manddata fields, Ehrenberg (2006) and Ehrenberg et al. (2007) focused on the Khuff reservoir porosity destruction and its syn-depositional and diagenetic causes. A review of Permian–Triassic reservoir rock properties, including the Upper Dalan, was recently presented based on re-examination of core, wireline and thin-section data from the Fars Province and the adjacent offshore by Esrafili-Dizaji and Rahimpour-Bonab (2013).

This study focusses on the microfacies, diagenesis, porosity–permeability relationships, and extensive anhydrite cementation of the Upper Dalan Formation in the Kish Gas Field, Zagros region, which is located at the southern end of the Zagros fold-and-thrust belt (Fig. 2). It is the first detailed study in the area that focuses on the influence of carbonate–evaporite facies and its diagenetic alterations on the reservoir heterogeneity, with the main goal to provide a better understanding of stratigraphy and reservoir complexity of this supergiant gas reservoir in the Middle East.

2. Geological setting

The Phanerozoic Zagros Basin is located between the central Iranian plateau in the NE, the Arabian Shield to the SW and the Taurides of Turkey to the NW (Alsharhan and Nairn, 1997; Bahroudi and Talbot, 2003). The tectonostratigraphy and evolution of the Zagros Basin has attracted the attention of geologists for decades due to its unique and complex geological history characterized by development of a multi-stage supergiant petroleum system (Sadooni and Alsharhan, 2004). Beside the sedimentation processes that resulted in more than 10 km thick sedimentary supersequence (Heydari, 2008), the history of Zagros Basin is marked by long periods of uplift without any sedimentation. The oldest sediments in the Fars Area date from the Precambrian and are composed of evaporitic facies of the Hormuz Formation. These salt deposits are overlain by Cambro-Ordovician mixed carbonate-siliciclastic shallow-marine succession (Bordenave, 2002). During Silurian period (Llandoverian), the entire basin has been flooded by a rapid sea-level rise that led to the creation of the organic-rich shale within an anoxic basin. This organic-rich shale has been interpreted to be the most prolific source rock for this basin, particularly for the Permo-Triassic reservoirs including the studied Dalan Formation. In the Fars area, the Hercynian uplift in the Devonian and Carboniferous (time-equivalent to the deposition of the Faraghan Formation in adjacent regions) caused a huge sedimentary hiatus. Szabo and Kheradpir (1978) suggested that the Permian (Dalan) and Triassic (Kangan) in the Zagros Mountains are separated by a significant unconformity during the Djulfian Stage; however, Bashari (2005) argues that such a major unconformity does not exist in the

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