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Chemical compaction features as potential barriers in the Permian-Triassic reservoirs of Southern Iran

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ABSTRACT

Chemical compaction features are important diagenetic imprints that generally interrupt reservoir quality in most carbonate reservoirs. In the Permian-Triassic reservoirs of South Pars Field, they are recorded in various types and intensities. High- to low amplitude stylolites and solution seams are concentrated within the K1–K4 units of the upper Dalan and Kangan formations, depending on their facies characteristics, diagenetic alterations and dominant lithology. In these units, there are some meaningful trends between the chemical compaction zones and sequence stratigraphic positions including the systems tracts of third-order sequences. Control of chemical compaction on reservoir characteristics is evaluated by using the results of petrographic studies, petrophysical logs and core poroperm measurements. Internal reservoir architecture of the studied reservoirs is determined using the both hydraulic flow units and stratigraphic modified Lorenz plot approaches. Identified baffle and barrier units show close correspondence with chemically-compacted zones. This indicates that zones with high concentration of stylolites and solution seams can be considered as small-scale vertical flow barriers in the Permian-Triassic reservoirs of South Pars Field.

1. Introduction

Besides facies characteristics and tectonically-induced features, diagenetic processes are among the main factors that control reservoir quality and fluid flow in carbonate reservoirs (Lucia, 2007; Ahr, 2008). As important diagenetic features, products of chemical compaction process, including the stylolites and solution seams, are complex column-and-socket structures that form as a result of pressure dissolution in both carbonate and clastic rocks during their residence in burial realms (e.g., Nenna and Aydin, 2011; Croize et al., 2013; Heap et al., 2014). They generally form when sediments experience high burial depth (around 0.8 to >2 km) due to an increase in overburden pressure and temperature (Railsback, 1993; Mallon and Swarbrick, 2008). In some cases, they have formed by tectonic activities. Tectonic-induced stylolites mostly occur as oblique, or sometimes, perpendicular to the bedding surfaces (Andrews and Railsback, 1997). Under such a high pressure–temperature condition, mineralogically unstable to metastable grains being dissolved at inter-grain junctions in forms of solution seams and stylolites (Ehrenberg et al., 2007). Dissolved materials and other fluids can migrate along the stylolites-paths to long distances and provide materials for other diagenetic features, such as burial cements. In this point of view, they can be considered as flow paths or conduits for fluid migration (Hassan, 2007; Heap et al., 2014).

On the other hand, they can act as flow barriers, when insoluble residual materials (such as clays, pyrite and oxides) accumulate in their paths and provide effective seals especially in vertical direction; i.e., perpendicular to the stylolite's plane (Burgess and Peter, 1985; Dutton and Willis, 1998; Alsharhan and Sadd, 2000). Therefore, characterization of stylolites, including their frequency, amplitudes and tightness, can help to get a better understanding about the reservoir heterogeneity in carbonate sequences (Oswald et al., 1995; Ehrenberg et al., 2007).

In the Persian Gulf, Permian-Triassic reservoirs were subjects of several studies that investigate their geological and structural history, sedimentary environment, sequence stratigraphy, hydrocarbon potential, and internal reservoir architecture (e.g., Pollastro, 2003; Insalaco et al., 2006; Maurer et al., 2009; Rahimpour-Bonab et al., 2010; Mehrabi et al., 2015). In most of these researches, chemical compaction features are reported as diagenetic features in these reservoirs. However, their detailed characteristics and

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controls on reservoir quality of concerned units are not yet thoroughly understood, especially in the South Pars Field. The main purpose of this paper is to describe the chemical compaction features, and investigate their relationships with lithological variations, facies associations, depositional sequences and reservoir heterogeneities in the Permian-Triassic reservoirs of South-Pars gas field in the Persian Gulf.

2. Geological setting and stratigraphy

Along with its southern extension (North Dome), the South Pars Field is the world's largest gas reserve that accumulated in the NNE–SSW trending Qatar Arch (QA) structure in the Persian Gulf (Fig. 1; Szabo and Kheradpir, 1978; AL-Jallal, 1995). This arc has bounded to the north and northeast by the Zagros fold and thrust belt (ZFTB) and is placed in the interior part of the Arabian Platform (Konert et al., 2001).

The Persian Gulf has been influenced by this regional gentle or broad anticline structure (Alsharhan and Nairn, 1997). During the late Precambrian to Early Cambrian, tectonic movements in central Saudi Arabia caused activation of fault systems and uplift in this area, i.e. the Qatar Arch. During the Silurian, source-rock intervals were deposited in the western and eastern parts of QA. Deposition of Permian-Triassic shallow marine carbonates and evaporites was initiated by an extensive marine transgression on the Arabian Plate during the Late Permian. This transgression was related to the opening of Neotethys Ocean and creation of a passive margin in the northeastern part of the Arabian Plate (Edgell, 1996; Sharland et al., 2001). These widespread carbonate-evaporite intervals were deposited as a blanket within which some individual horizons are correlatable over wide distances throughout the Persian Gulf.

The Late Permian to Early Triassic carbonate-evaporite units of the South Pars Field have been divided into the Dalan and Kangan formations (Khuff equivalents), respectively (Fig. 2; Kashfi, 2000). Due to Late Triassic tectonic movements in the QA, there was no sedimentation in these sub-basins from latest Triassic to Middle Jurassic times (Murris, 1980). Stratigraphic successions in the subsurface of the QA consist of (Fig. 2):

- The post-Precambrian to the pre-Permian clastic sediments (including Silurian source rocks);
- The Permian-Triassic sequences of thick limestones, dolomites and anhydrites, (Khuff equivalents) in the Arabian Plate (as reservoir rocks);
- The post-Triassic section, predominantly marine sequences of limestones, dolomites, shales and evaporites with local sandy clastic sequences.

Stratigraphically, the Dalan Formation (Late Permian) is commonly divided into four units named as K3, K4, Nar member, and K5. Among these, the K4 and K5 units are mainly composed of dolomite and limestones with some anhydritic intervals. The K3 unit consists of dolomite and dolomitic limestone. The Early Triassic Kangan Formation is divided into K2 (limestone and dolomite) and K1 (anhydrite, dolomite and limestone) units (Fig. 2). The main reservoir intervals of these formations are K2 and K4 units, in which high energy shoal facies (mainly ooid grainstones to packstones) provided thick, porous, and permeable intervals that produce the main portion of gas in the South Pars Field (Ehrenberg, 2006; Tavakoli et al., 2010). This study focuses on the K1–K4 units of these reservoirs that correspond with the upper Dalan and Kangan formations.

3. Materials and methods

This study is based on the data from five exploration wells

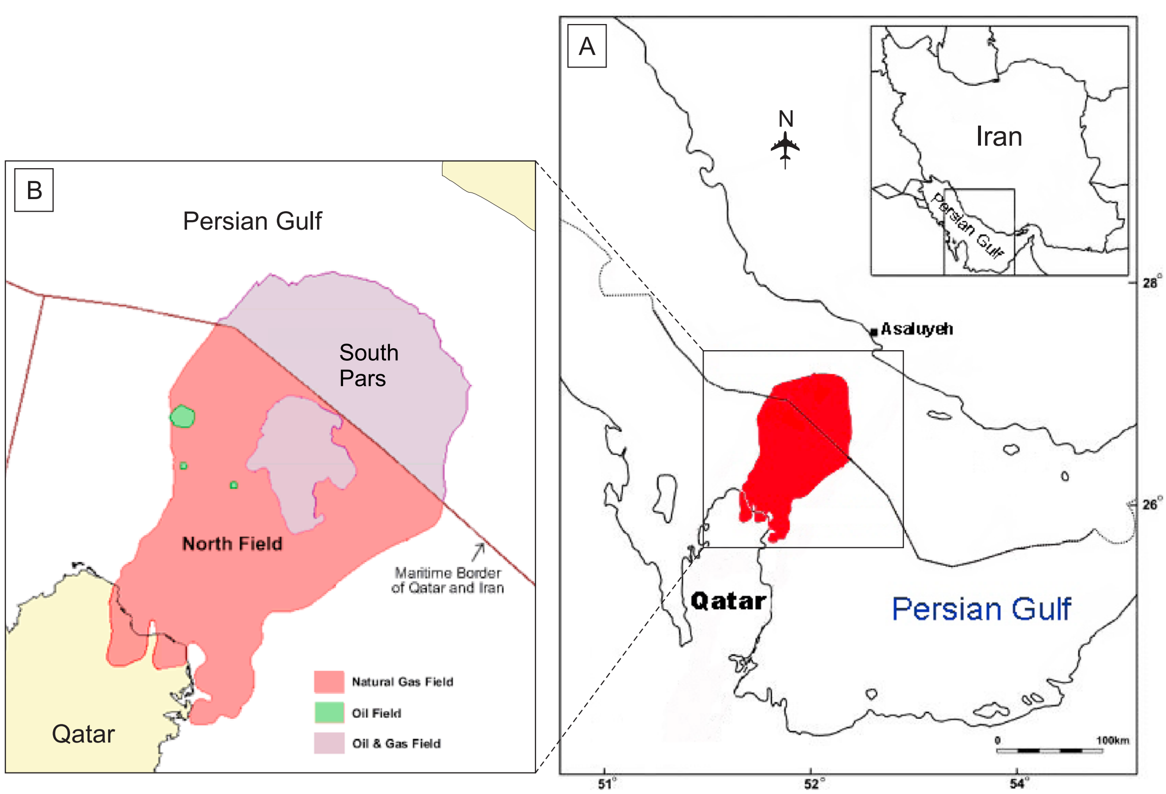

Fig. 1. A-Location map of the Persian Gulf and South Pars Field on the Qatar-Arc structure. B-Detailed location map of the studied field in the Persian Gulf of Southern Iran.