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Understanding the fracture role on hydrocarbon accumulation and distribution using seismic data: A case study on a carbonate reservoir from Iran

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ABSTRACT

The South Pars, the largest gas field in the world, is located in the Persian Gulf. Structurally, the field is part of the Qatar–South Pars arch which is a regional anticline considered as a basement-cored structure with long lasting passive folding induced by salt withdrawal. The gas-bearing reservoir belongs to Kangan and Dalan formations dominated by carbonate rocks. The fracture role is still unknown in gas accumulation and distribution in this reservoir. In this paper, the Scattering Index (SI) and the semblance methods based on scattered waves and diffraction signal studies, respectively, were used to delineate the fracture locations. To find the relation between fractures and gas distribution, desired facies containing the gas, were defined and predicted using a method based on Bayesian facies estimation. The analysis and combination of these results suggest that preference of fractures and/or fractured zones are negligible (about 1% of the total volume studied in this paper) and, therefore, it is hard to conceive that they play an important role in this reservoir. Moreover, fractures have no considerable role in gas distribution (less than 30%). It can be concluded from this study that sedimentary processes such as digenetic, primary porosities and secondary porosities are responsible for the gas accumulation and distribution in this reservoir.

1. Introduction

The Qatar–South Pars arch located in the Persian Gulf is the host of the largest offshore gas field in the world. This field is shared between Iran and Qatar and it is called South Pars in the Iranian sector and North field in the Qatari sector. This gentle northeast–southwest mega-anticline is considered as a basement-cored structure (Al-Husseini, 2000; Edgell, 1996; Konert et al., 2001; Talbot and Alavi, 1996) while salt withdrawal induced a passive folding on it (Perotti et al., 2011). Regional seismic sections show a first order structure with a thick sedimentary cover and no major fault (Perotti et al., 2011). On the other hand, geophysical well logs and core data indicate carbonate rocks as the major lithology for the reservoir with less frequent fractures (Tavakoli et al., 2011). Understanding the fracture properties like frequency, location, density, orientation and their effects on porosity and permeability are crucial parameters in both exploration and production stages. Fractures are the most important types of porosities in carbonate reservoirs controlling hydrocarbon accumulation and forming the high permeable zones (Narr et al., 2006). Nelson (2001) classified scale of natural fractures to tectonic, regional, surface-related and constructional fractures, respectively, from large to small scale. Seismic wave often reacts against fractures in various manners except for the constructional fractures. A better knowledge about natural fractures and their geometry and locations can be not only helpful to better understand naturally fractured reservoir, but also their prediction limits (Narr et al., 2006). The current opinion by the National Iranian Oil Company (NIOC) is that there is not enough evidence to consider the reservoir as a fractured reservoir, however, the role of fractures are not exactly known (personal communication, NIOC, 2012). This paper uses the well and seismic data from parts of the South Pars field to better understand the role of fractures by delineating them using various diffraction-based methods. Also, their effect on hydrocarbon distribution is further studied by combining the fracture delineation results with estimated facies distribution.

Amplitude variations with azimuth (AVAZ) (Ali and Jakobsen, 2011; Minsley et al., 2003; Rüger, 1998, 2002; Tsvankin et al., 2012; Zheng, 2006), seismic attributes (Al-Dossary and Marfurt, 2006; Chopra and Marfurt, 2010; Chopra et al., 2011) and scattered waves and diffraction studies (Bellefleur et al., 2012; Malehmir and Bellefleur, 2009; Malehmir et al., 2009, 2010; Schmelzbach et al., 2008; Willis et al., 2006) are some of the most common methods to detect seismic scale fractures and their properties. In this paper two methods based on scattered waves and diffraction studies are used to initially delineate the fractures assuming that they would influence the seismic wavefield. It is believed that

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fractures and/or fracture zones scatter or diffract the incoming wave (Fang et al., 2013; Sheriff and Geldart, 1995). Willis et al. (2006) developed a method, called Scattering Index (SI), to estimate reservoir fracture distribution and orientation. This method provides maps of scattered energy associated with the presence of fracture corridors at the reservoir level. On the other hand, a fracture zone, depending on its size and geometry, may also generate diffractions. Schmelzbach et al. (2008) modified a conventional zero-offset Kirchhoff migration routine, semblance migration method, to locate diffracted energy at the expense of specular reflections.

To find the relation between fractures and gas distribution across the reservoir, a Bayesian facies prediction procedure can be used (Buland et al., 2008; Grana and Della Rossa, 2010; Karimpouli et al., 2013). According to this approach, a combination of three conditional distributions with a Bayesian classification is used to predict the probability of different facies with associated uncertainties. Karimpouli et al. (2013) applied the Bayesian approach in this carbonate reservoir and predicted the favorable facies across the reservoir. In this study, the implemented facies prediction is totally based on their work. They suggested that porosity, frame flexibility factor and bulk modulus of fluid are the proper rock physics parameters for the facies study in this reservoir and mapped the distribution of facies for a 2D section of the reservoir.

In this study, a 3D cube of unmigrated stack seismic data is used for fracture delineation. To find out the facies distribution, a 3D cube of prestack migrated seismic data in three different incident angles is also used. In addition, well logs, core data and special core analysis (SCAL) from one well are used.

In the following sections, general and structural geology are presented. In the main part of the study, fractures are delineated using the two-mentioned methods and, then, the desired facies are defined and estimated using the Bayesian approach. Finally, all results are combined and integrated to explain the role of fractures and their importance in hydrocarbon accumulation and facies distribution in the reservoir.

2. General and structural geology

The Qatar–South Pars arch is a major anticline (more than 100 km wide and 300 km long) with a northeast–southwest direction from the Qatar peninsula to the central Persian Gulf separating it into two basins characterized by a significant Proterozoic-Hormoz salt diapirism (Fig. 1). The arch is part of the Arabian platform considered as a first order structure from a tectonic point of view. A 14 km thick (Perotti et al., 2011) sedimentary cover of Arabian platform is warped through the Iranian platform by this arch. Arabian platform is considered as a sedimentary basin covered by sediments from Late Proterozoic to Holocene on the northeastern margin of the Arabian sector of Gondwana (Konert et al., 2001; Ziegler, 2001).

The absence of salt-related structures on the crest of the Qatar–South Pars arch is a strong reason to consider it as cored by an Infracambrian basement horst block, initiated during the Infracambrian Najd rifting (Al-Husseini, 2000; Konert et al., 2001) (Fig. 1). These deep structures have been repeatedly reactivated during the Phanerozoic, triggering the uplift of salt diapirs (Edgell, 1996) and basement-cored structures (Wender et al., 1998), and controlling the geometry and deposition of the overlying sedimentary cover (Edgell, 1996; Konert et al., 2001; Pollastro, 2003).

A regional 2D seismic section has been interpreted in the Iranian sector of the Central Persian Gulf by Perotti et al. (2011) (Fig. 1). The section (Fig. 2) contains a series of reflectors forming a gentle fold with almost flat limbs (0.4–0.7° at the top of the Permian) (Perotti et al., 2011). According to basement cored structure, basement highs can be interpreted as the core of the Qatar–South Pars arch.

The Qatar–South Pars arch in Fig. 2 can be determined using a traditional approach of mapping the areas without salt-related structures. There are two structures which can be interpreted as salt diapirs. Diapir A is the closest salt to the crest of the arch (Dukhan anticline). Diapir B is characterized by the circular feature in Fig. 3 corresponding to the seismic transparent zone bordered by concave reflectors visible in the regional section (Fig. 2) (Perotti et al., 2011).

3. Reservoir geology

In the South Pars field, gas reservoirs are mostly limited to the Permian–Triassic stratigraphical units which are Faraghan (Early Permian), Dalan (Late Permian) and Kangan (Early Triassic) formations shown in Fig. 3 (Kashfi, 2000). Kangan and Dalan formations, known as Khuff formation in the Arabian plate (Tavakoli et al.,

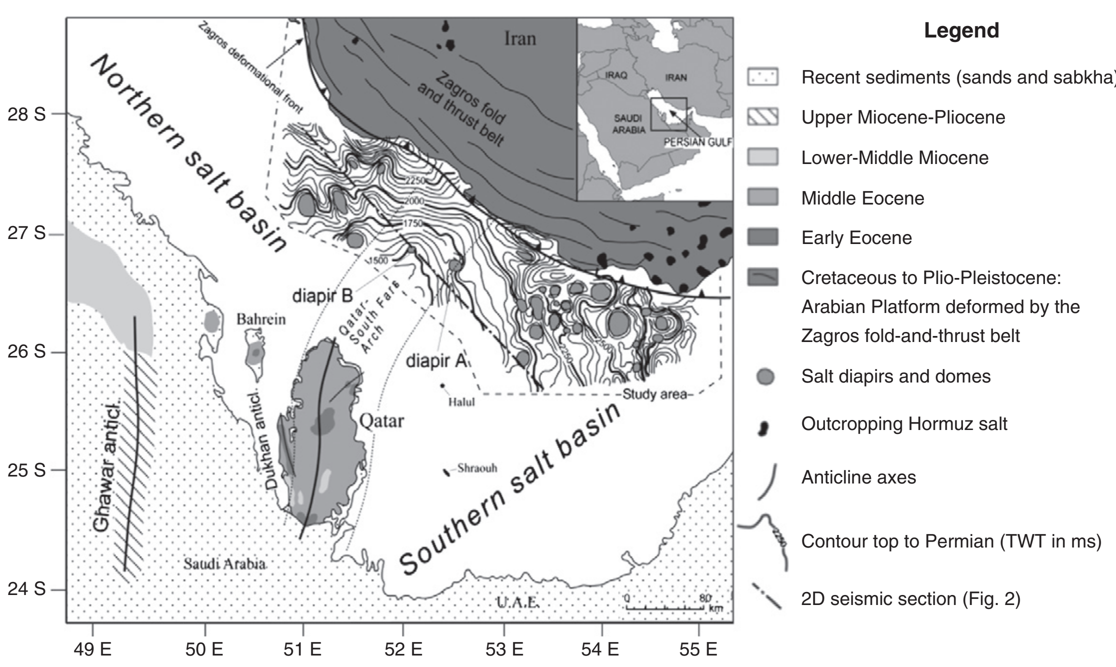

Fig. 1. Simplified geologic map of Arabian and Iranian Platforms in the Persian Gulf. Seismic contour map showing two-way time (in ms) of near top Permian (modified from Perotti et al., 2011).