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Characterization of the Qishn sandstone reservoir, Masila Basin–Yemen, using an integrated petrophysical and seismic structural approach

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ABSTRACT

This study presents an integrated petrophysical and seismic structural analysis that is carried out to evaluate the reservoir properties of Qishn sandstone as well as the entrapment style of the hydrocarbons at Sharyoof field, Sayun-Masila Basin that is located at the east central of Yemen. The reservoir rocks are dominated by clean porous and permeable sandstones zones usually intercalated with some clay stone interbeds. As identified from well logs, Qishn sandstone is classified into subunits (S1A, S1B, S1C and S2) with different reservoir characteristics and hydrocarbon potentiality.

A number of qualitative and quantitative well logging analyses are used to characterize the different subunits of the Qishn reservoir and identify its hydrocarbon potentiality. Dia-porosity, M-N, Pickett, Buckles plots, petrophysical analogs and lateral distribution maps are used in the analysis. Shale volume, lithology, porosity, and fluid saturation are among the most important deduced parameters. The analysis revealed that S1A and S1C are the main hydrocarbon-bearing units. More specifically, S1A unit is the best, as it attains the most prolific hydrocarbon saturations (oil saturation "SH" up to 65) and reservoir characteristics. An average petrophysical ranges of 4–21%, 16–23%, 11–19%, 0–65%, are detected for S1A unit, regarding shale volume, total and effective porosity, and hydrocarbon saturation, respectively. Meanwhile, S1B unit exhibits less reservoir characteristics (Vsh>30%, ϕEff<15% and SH< 15%).

The lateral distribution maps revealed that most of the hydrocarbons (for S1A and S1C units) are indicated at the middle of the study area as NE–SW oriented closures. The analysis and interpretation of seismic data had clarified that the structure of study area is represented by a big middle horst bounded by a group of step-like normal faults at the extreme boundaries (faulted anticlinal-structure). In conclusion, the entrapment of the encountered hydrocarbon at Sharyoof oil field, seems to be due to the combined effect of the stratigraphic position of the Qishn reservoir clastics with their overlying thick-sealing sediments and the structural setting as represented by faulted anticlinal-structure associated with the bounding step-like normal faults.

1. Introduction & exploration history

The first exploration activities for hydrocarbons in Yemen began at the end of 1960s in the coastal region of the Red Sea being the first target of these activities in 1961. The first commercial discovery was made in 1982 in the central part of the Marib–-Shabwa Basin (block-18 at central Yemen) by an American oil company named "Yemen Hunt Oil Company". A production rate of 8000 B/D was started by the same company during the summer of 1986 from the Alif Field through the Alif-1 well (Alareeq and Alaug, 2013; Alaug et al., 2013). In general, the complex political history of Yemen contributed to a remarkable lack of petroleum exploration until the discovery of Alif field in North Yemen in the Ma'Rib–Al Jawf/Shabwah basin in 1984 (Beydoun, 1966, 1989; Fairchild, 1992; Schlumberger, 1992; Petroconsultants, 1996; Bosence, 1997;

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Maycock, 1997; Nabawy and Al-azazi, 2015).

The Sayun–Masila Basin is one of the most productive basins in the Republic of Yemen. In 1991, significant oil discoveries followed by more findings, were made on Sounah Field at Masila block (Block-14) by Canadian Oxy Company (now PetroMasila). Then, the block was developed by building its plants and construction of the oil pipeline to Al-Dhabah (Ash Shihr) area, Hadhramout governorate, on the Arab Sea. In 1998, Total E&P Yemen (Total Fina Alf) made a number of oil discoveries in the fields of Kharir, Atouf, and Wadi Taribah, (East Shabwah block-10). Production was linked with Masila block-14. On December 18, 1999, DNO, a Norwegian company as operator of Hwarim block-32 announced the discovery of oil and started production and exporting oil through Masila pipeline by November 2001(PEPA, 2014).

The Sharyoof oil field is situated in the onshore of Block-53 in the Masila basin. Block-53 was awarded to Dove in 1998 in relinquished acreage that is located adjacent to the prolific Block-14 (contains 16 producing fields) and operated by Nexen Petroleum Yemen Ltd (Dove, 2000). Sharyoof filed was discovered by Dove Energy in 2000 by drilling the second exploration well that is located 550 km east of Sana'a city, the Yemeni capital. On December 17, 2003, Nexen announced the first oil commercial discovery. It started production and exporting oil through Masila pipeline in November 9, 2005 (PEPA, 2014). Successful exploration and appraisal drilling through 2007 and 2008 has provided 4 wells already completed for production from block-53. In 2008 well production capacity is more than 5000 B/D. Oil samples were recovered from both Qishn sandstone and Kholan sandstone.

The aim of this work is to enhance comprehensive petrophysical analysis for of the different units of the Qishn sandstone reservoir, beside identifying the seismic structural and entrapment style of the implied hydrocarbons. A number of qualitative and quantitative well logging analyses are carried out to deduce the necessary parameters for reservoir evaluation and characterization. Seismic data are analyzed and a number of 2D seismic sections are constructed and interpreted. The applied methodology follows the standard well logging and seismic data procedures, as well as the analyses done in areas of similar hydrocarbon characteristics (Serra, 1986; Schlumberger, 1992, 1996; Asquith and Krygowski, 2004; Lashin and Abd El Aal, 2004; Petroconsultants, 1996; Abd El Naby et al., 2009; Nabawy et al., 2009; da Silva and Coutinho, 2011; Almuhaidib et al., 2012; Lashin and Serag El Din, 2013; Lashin and Abd El Naby, 2014; Lashin et al., 2011, 2014; Jafri et al., 2015; Nabawy and Al-azazi, 2015; etc.).

2. Geological setting

The Sharyoof oil field is faulted anticline structure present in Block-53 at the northeastern portion of the Masila Basin, towards the east of Hadhramout Province, Yemen. Block-53 is located between several successful producing oil fields: the Sunah Field in the Masila Block to the south east (Block-14); the Kharir Field to the west (East Shabwah Block "Block-10″) and the Tasour oil discovery to the east of Block-32 (Dove, 2000; PEPA, 2007; see Fig. 1).

The Masila basin which is an irregular-shaped concession falling in an area covering about 1250 km^2, was initiated as a rift basin during Upper Jurassic-Early Cretaceous Post-Pangea breakup (Bosence, 1997; Redfern and Jones, 1995; and Omran and Alareeq, 2013). Rifting caused a series of northwest-southeast and west-east-trending major basin-bounding faults evolving, adjacent to which three main Jurassic-Cretaceous rift graben basins are located, i.e., the Marib-Shabowah, the Masila, and the Jiza'-Qamar Basins (Beydoun et al., 1998). The tectonic evolution of the Masila Basin can be divided into three stages: Pre-rift, Syn-rift and Post-rift (see stratigraphic column, Fig. 2).

Pre-rift megasequence ranges in age from Proterozoic to early Late Jurassic. The Pre-rift has been reached and penetrated by wells drilled in the Masila Basin. The basement of the Masila basin consists mostly of igneous and metamorphic complex rocks of Proterozoic to early Cambrian age. This basement complex is overlain unconformably by a Jurassic sequence. In Early to Mid Jurassic time, sandstone was deposited widely across Yemen (Kuhlan Formation), where thick sedimentation developed in lows formed before Jurassic time. In Masila Basin oilfields, the sandstone of the Kuhlan Formation is very fine-to medium grained, well-sorted, and poor to good porosity. After deposition of the Kuhlan Formation, another marine transgression from the southeast reworked the sandstone and deposited shallow-marine carbonates (Shuqra Formation). The Shuqra Formation is Middle to Late Jurassic in age and consists predominantly of platform carbonate (PEPA, 2014).

During the syn-rift sequence, horsts and nested fault blocks were developed, where differential compaction and drape anticlines occurred in the Upper Jurassic to Lower Cretaceous due to basement highs (Redfern and Jones, 1995; Canadian Oxy Company, 2001). Upper Jurassic sediments, known as the Madbi Formation, were penetrated by wells drilled in the basin. This formation is generally composed of porous lime-grainstone to argillaceous lime mudstone. The lower part of this formation is commonly argillaceous lime and basal sand, and forms a good reservoir in some oil fields of the Masila Basin (Canadian Oxy Company, 2003). The upper member is called Madbi shale and is composed of 30–100 m laminated organic-rich shale and mudstone (Mills, 1992). During latest Jurassic to Early Cretaceous time, the rifting in the Masila Basin continued, but the subsidence became slower. It was accompanied by the accumulation of carbonates as shallow-marine shelf deposits which constitute the Naifa Formation. The Naifa Formation consists mainly of silty and dolomitic limestone and lime mudstone with wackestone. The upper part of this formation is composed of very porous clastic carbonate overlain by the Saar dolomite facies. The Saar Formation is composed mainly of limestone, dolomitic limestone with some mudstone, and sandstone (Canadian Oxy Company, 1999).

The Post-rift megasequence ranges in age from late Early Cretaceous to Tertiary time and rests unconformably on the syn-rift section. Late Early Cretaceous sediments, known as the Qishn Formation, consist of braided plain to fluvial and shallow-marine sediments deposited in the Masila Basin. The Qishn Formation is divided into two members, Upper Qishn Carbonate and Lower Qishn Clastic Members. The Upper Qishn Carbonate Member consists of laminated to burrowed lime mudstone and wackestone interbedded with terrigenous mudstone and black fissile shales. These sediments were deposited in deep water under alternating open and closed marine conditions (Beydoun et al., 1998). The Qishn Clastic Member is composed mainly of sandstones, with shale and minor carbonate interbeds, deposited in braided river channels, and in shoreface and shallow-marine settings (King et al., 2003; Leckie and Rumpel, 2003). The Qishn Clastics Member is also referred to as the Biyadh Formation, in comparison to the Biyadh Sandstone in Saudi Arabia (Redfern and Jones, 1995) and correlates with the Zubair Formation in the Kuwait and Iraq (Davies et al., 2002).

During the late Early Cretaceous, alternating regression and transgression occurred. This pattern deposited clastic (Harshiyat Formation) and carbonate rocks (Fartaq Formation) interbedded with each other. A similar pattern of sedimentation occurred in Upper Cretaceous time, where fluvial systems (Mukulla Formation) prograded southeast ward in the Masila Basin. The Late Cretaceous Sharwayn Formation deposits are composed mainly of shale. The overlying Tertiary units comprise homogeneous argillaceous, detritus carbonates and hard, compacted, massive and bedded