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Controls of grain-size distribution on geomechanical properties of reservoir rock—A case study: Cretaceous Khafji Member, Zuluf Field, offshore Arabian Gulf

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Abstract

The Khafji Member of the Cretaceous Wasia Formation in Zuluf Field, offshore Saudi Arabia is an important siliciclastic hydrocarbon reservoir. The reservoir consists of a lower Main Sand and an upper Stringer Sand. The present study investigated the relationships between the geomechanical attributes (Young's modulus and Poisson's ratio) of the reservoir and its grain size distribution. In addition, an attempt was also made to relate the reservoir quality with the depositional environments deduced from factor analysis of the grain size distribution data.

The Young's modulus for the Khafji reservoir range from a low of 8.43×10^5 psi at 1000 psi confining pressure (1.13×10^6 psi at 2900 psi confining pressure) to a high of 1.27×10^6 psi at 1000 psi (1.91×10^6 psi at 2900 psi). The study shows that there is no significant relationship between grain size parameters (mean, median, skewness, and kurtosis) and geomechanical properties. However, a good correlation was observed between geomechanical parameters and sands deposited in different environments. The clean sand showing moderate to good sorting and interpreted as beach sand showed low Young's modulus (average 1.07×10^6 psi) and Poisson's ratio (average 0.16), while the parameters were higher (average of 1.57×10^6 psi Young's modulus and 0.204 Poisson's ratio) for the fine-grained sediments representing possible lagoonal or offshore environment.

Keywords: Geomechanical; Sandstone; Reservoir; Size analysis; Petroleum; Saudi Arabia; Offshore; Borehole stability

1. Introduction

Rock-mechanical properties of reservoir rocks are important in formulating the strategies related to well drilling and completion, reservoir stimulation and production, and monitoring of reservoir processes (Meehan, 1994; Bjorlykke and Hoeg, 1997). The most important extrinsic factors controlling rock-mechanical properties are confining pressure and strain rate. The important intrinsic geological factors include porosity, grain size, mineralogy, and types of cement (Donath and Fruth, 1971; Plumb et al., 1992; Sarda et al., 1993). Since rocks are the host of oil and gas, their mechanical behavior and factors is important in both exploration and development processes of a reservoir.

A number of authors including Bell (1978), Fahy and Guccione (1979), Ghafoori et al. (1993), Ulusay et al. (1994), Shakoor and Brown (1996), Topal and Doyuran (1997), Bell et al. (1999), Chatterjee and Mukhopadhyay (2001), and Jeng et al. (2004) have discussed the relationships between sedimentological attributes grain size, petrographical characteristics, etc. with the geomechanical properties of reservoir rocks. The present study evaluates the control of grain-size distribution and depositional environment on geomechanical properties (Young's modulus and Poisson's ratio) of the Cretaceous Khafji reservoir, Zuluf Field, offshore Saudi Arabia (Fig. 1).

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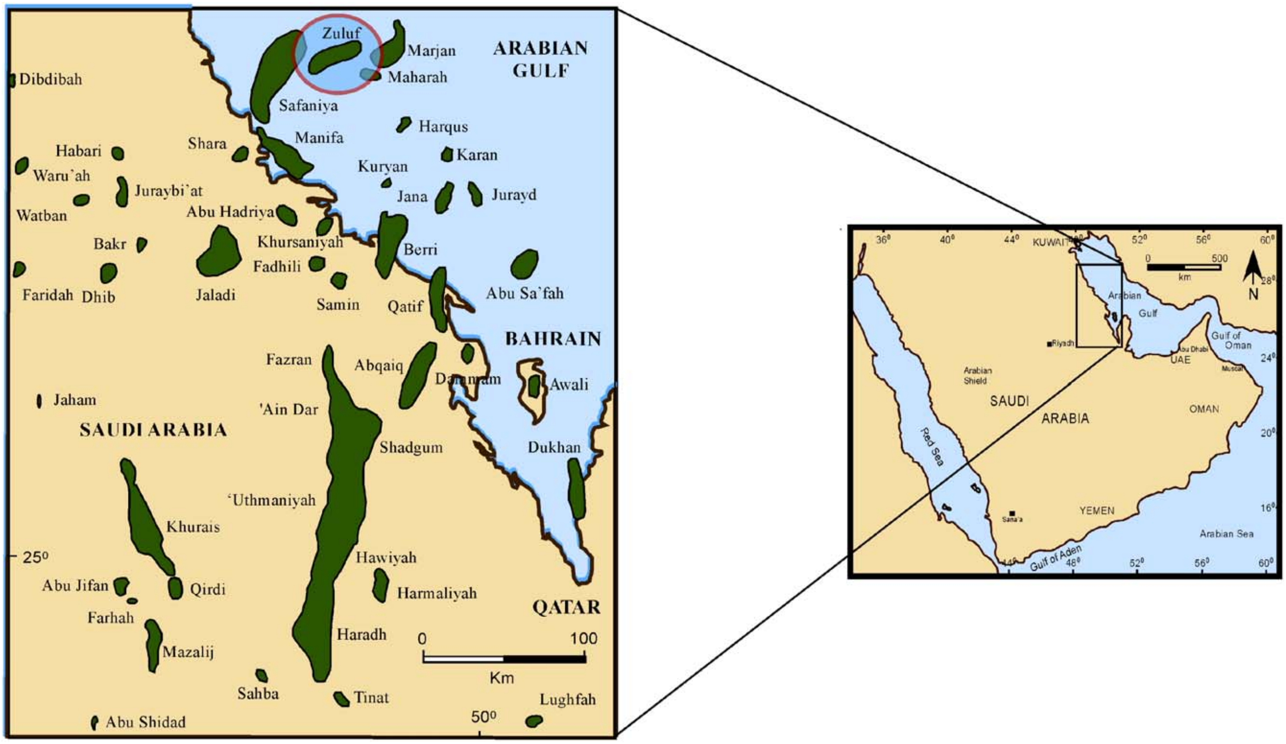

Fig. 1. Location map of the study area. Zuluf Field is a giant offshore oil field located northwestern part of the Arabian Gulf.

2. Methodology

In order to determine the control of the geological parameters on the mechanical properties, the reservoir rock (sandstone) was characterized based on textural and petrographic attributes. For this purpose, a total of 40 core samples were sieved at a grain size interval of 0.5φ using a mechanical shaker. The average weight of the samples used for sieving was approximately 20 g. The size distribution of the different fractions was normalized before plotting on a semi-log probability paper for the purpose of characterizing the sediments following the method outlined by Visher (1965). Statistical parameters such as median, mean, sorting, skewness, and kurtosis were calculated following the graphic method outlined by Folk (1974). The grain size distribution data was also subjected to Q mode factor analysis using a commercially available statistics package, Statistica.

Young's modulus (E) and Poisson's ratio (v) related to different confining stresses were correlated with the grain size parameters of the Khafji reservoir. These rock-mechanical properties were measured from core samples collected at different depth intervals of the well. Triaxial strength measurements were made on 0.5 in. diameter by 3.0 in. long vertical core plugs obtained from different depths of the reservoir. The measurements were made in a triaxial cell by recording axial and radial strain as the sample was loaded in the triaxial loading mode. Two different confining stresses were used (1000 and 2900 psi). Young's modulus and Poisson's ratio corresponding to the 50% of the failure load were then calculated.

3. Khafji reservoir

The Khafji reservoir is a part of the Khafji Member of the Middle Cretaceous Wasia Formation (Fig. 2). The Khafji Member overlies the Lower Cretaceous Shu'aiba Formation and in turn is conformably overlain by Safaniya Member. The Khafji Member in the Zuluf Field consists of a thick (up to 680 m) sequence of quartz sandstone, siltstone, shale, various types of ironstone, and minor amounts of limestone, amber, and few scattered coal beds. The Khafji reservoir in Zuluf Field is divided into Main Sand and Upper Stringer Sand (Fig. 3).

The reservoir interval of the Khafji reservoir is a medium to coarse-grained fluvial to shallow-marine loose sandstone. Compositionally, the sandstone is a quartz arenite (Fig. 4) with dominant minerals represented by quartz (up to 98%) and feldspar (up to 2%). Other components of the sandstone comprise chert (up to 5%), matrix (up to 30% in muddy intervals), and opaques (up to 8%). Both X-ray diffractometry (XRD) and scanning electron microscopy (SEM) confirmed that kaolinite is the dominant component of the clay matrix (Fig. 5). The porosity of the reservoir ranges from 6.8% to 34.8% (average of 20.8%), and is mainly intergranular. The permeability of the Khafji sandstone varies widely, ranging from a low of 0.04 millidarcies (md) in mud-rich horizons to over 784 md in