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Seismic reservoir characterization of a deep water sandstone reservoir using hydraulic and electrical flow units: A case study from the Shah Deniz gas field, the South Caspian Sea

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ABSTRACT

Seismic reservoir characterization of deep water sandstones using hydraulic and electrical flow units plays an important role in delineation of oil and gas traps in the Caspian Sea basin. The proposed methodology of this study comprises two major steps. Firstly, the reservoir rock types, including Hydraulic Flow Units (*HFUs*) and Electrical Flow Units (*EFUs*) are estimated from petrophysical data. Secondly, seismic data are converted into *HFUs* and *EFUs* by using the seismic attributes technology in conjunction with the neural networks and fuzzy clustering algorithms. Optimal seismic attributes for the estimation of Current Zone Index (*CZI*) and Flow Zone Indicator (*FZI*) include acoustic impedance, which was derived from a model based inversion, together with dominant frequency and amplitude envelope data. High porosity and permeability zones are delineated by using the seismic derived flow zone indicator data. Since there is a strong correlation between water saturation and current zone indicator, hydrocarbon saturation changes within the sandstone packages are investigated by using the EFU model. The integrated approach introduced in this study is successful in highlighting high porosity and low water saturations zones of the Shah Deniz sandstone packages.

1. Introduction

The success degree of many oil and gas drilling, completion and production activities depends on the accuracy of models used in a reservoir description procedure. A detailed knowledge of porosity and permeability distribution within reservoir rocks facilitates both identification of high quality zones and selection of optimal well locations. The hydraulic flow units concept has widely been used in reservoir characterization (Amaefule et al., 1993; Abbaszadeh et al., 1996; Elkewidy, 1996; Al-Ajmi and Holditch, 2000; Prasad, 2003; Svirsky et al., 2004; Amabeoku et al., 2005; Aggoun et al., 2006; Kadkhodaie-Ilkhchi and Amini, 2009; Crandall et al., 2010). A new method has also been introduced by Rezaee et al. (2007) to classify formation factor (*F*) and porosity into separate electrical flow units (*EFUs*) using current zone indicator (*CZI*). Moreover, prediction of subsurface physical properties has always been a fundamental problem confronting geologists and geophysicists. Hitherto, several researchers have studied on prediction of petrophysical properties from seismic data using statistical methods and intelligent systems (Nikravesh et al., 1998; Todorov et al., 1998; Hampson et al., 2001; Nikravesh and Aminzadeh, 2001; B.H. Russell, 2004; Kadkhodaie-Ilkhchi et al., 2009). Seismic attributes have successfully been used to predict reservoir properties (B. Russell et al., 1997; Pearson and Hart, 1999; Hart and Balch, 2000). The main purposes of this study are as follows: (a) studying a deep water sandstone reservoir from the view point of hydraulic and electrical properties in the largest natural gas field of Azerbaijan; (b) propagation of hydraulic and electrical flow units through seismic attributes; (c) making a comparison between *HFUs* and *EFUs* in well profile and seismic section; and (d) studying the connection between seismic derived flow units and reservoir quality of sandy packages.

2. Study area

The Caspian Sea is one of the most important regions in the world for petroleum resources and a major supplier for oil and gas to European markets. Shah Deniz gas field is the largest natural gas

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Nomenclature

a	tortuosity factor
CZI	current zone indicator
EFU	electrical flow unit
ERI	electrical radius indicator
ε	pore to matrix volume ratio
F	formation factor
φ	formation porosity
FCM	fuzzy C-means clustering
FZI	flow zone indicator
HFU	hydraulic flow unit
k	formation permeability
La	mean path length of porous medium
L	straight line of porous medium length
m	cementation exponent
n	saturation exponent
PMR	pore to matrix volume ratio
PNN	probabilistic neural network
RQI	reservoir quality index
Rt	true formation resistivity
Rw	formation water resistivity
SP	sandy packages
Sw	water saturation

field in Azerbaijan. It is situated in the South Caspian Sea, off the coast of Azerbaijan, approximately 70 km (43 mile) southeast of Baku, at a depth of 600 m (2000 ft). The field covers approximately 860 km^2 (330 mile^2). The Shah Deniz gas and condensate field was discovered in 1999.

Deep hydrocarbon accumulations below 5000 m have been discovered in the South Caspian basin at the end of 20th century. The giant structure developed during the Pliocene as a doubly plunging anticline over the last 3 Ma, with approximately 2 km of vertical relief and 360 km^2 of four-way dip closure. The world class reservoir and source rock systems in the drainage area are regionally extensive and focused fluid flow-water and petroleum-into the overpressured core of the anticline. Seal capacity of petroleum accumulation was restricted and limited column height of stacked pays. A recent regional uplift and erosion event is the likely cause for a large scale depressurization which created pressure regression in a number of regionally extensive reservoirs. Indications of tilted petroleum contacts in some reservoirs can be interpreted as expression of an active hydrocarbon aquifer. Three main gas reservoirs of the Shah Deniz field include sandstones of Balakhani VIII formation and Sandy Packages II & III of Fasila group.

The good pay zones within the structure are expected to be at a total depth of 5–6.5 km and they have been folded into a relatively simple dip-closed anticline structure. Recoverable reserves for the first stage of development are put at 22.1 trn ft^3 of gas and 750 m barrels of condensate. Location map of the Shah Deniz gas field and exploration wells are shown in Fig. 1.

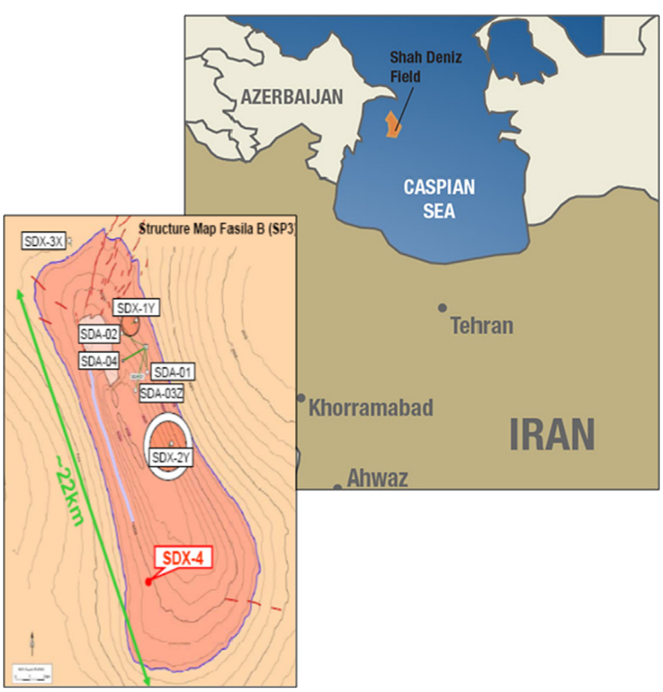

Fig. 1. Location map of Shah Deniz field and exploration wells (Whear, 2004).

3. Methodology

In this study, hydraulic and electrical flow units were estimated from well and seismic data by using intelligent systems. Prior to flow units determination well logs were processed and quality controlled. A depth matching procedure was carried out to ensure the correct reading of well logs against core data. Raw well logs were environmentally corrected and outlier data were removed. Petrophysical evaluation was done by using probabilistic models. Log uncertainties were adjusted to obtain the reliable results in comparison to available core data. The main mineralogy is sandstone and shale. Indonesia equation with the modified Archie parameters was used for water saturation calculation.

3.1. Determination of hydraulic flow units (HFUs)

Hydraulic flow units are defined as the correlatable and mappable zones within a reservoir, which control fluid flow (Ebanks, 1987). Each flow unit is characterized by an *FZI*, which can be defined in terms of the relationship between the volume of void space (ε) and geometric distribution of pore spaces (quantified as reservoir quality index, *RQI*) as follows (Amaefule et al., 1993):

$$\log RQI = \log FZI + \log \varepsilon \tag{1}$$

where

$$\varepsilon = \varphi/(1-\varphi) \tag{2}$$

RQI and *FZI* can be calculated using the following equations:

$$RQI = 0.314\sqrt{k/\varphi} \tag{3}$$

$$FZI = 0.314/\varepsilon\sqrt{k/\varphi} = RQI/\varepsilon \tag{4}$$

where k is permeability (milli Darcy, mD), φ is fractional porosity and ε is pore to matrix volume ratio ($\varepsilon = \varphi/(1-\varphi)$). Rocks with a narrow range of *FZI* values belong to a single hydraulic unit, i.e. they have similar flow properties (Prasad, 2003). The relationship between ε and *RQI* was used to show that samples with similar *FZI* values lie close together on a semi-log plot of porosity versus permeability (Amaefule et al., 1993). The porosity–permeability relationship on a plot can be defined individually for each hydraulic unit. The permeability variation in a given reservoir is found in relation to the hydraulic units with similar *FZI* values (Amaefule et al., 1993).