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Reservoir zonation based on statistical analyses: A case study of the Nubian sandstone, Gulf of Suez, Egypt

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ABSTRACT

Both reservoir engineers and petrophysicists have been concerned about dividing a reservoir into zones for engineering and petrophysics purposes. Through decades, several techniques and approaches were introduced. Out of them, statistical reservoir zonation, stratigraphic modified Lorenz (SML) plot and the principal component and clustering analyses techniques were chosen to apply on the Nubian sandstone reservoir of Palaeozoic – Lower Cretaceous age, Gulf of Suez, Egypt, by using five adjacent wells. The studied reservoir consists mainly of sandstone with some intercalation of shale layers with varying thickness from one well to another. The permeability ranged from less than 1 md to more than 1000 md. The statistical reservoir zonation technique, depending on core permeability, indicated that the cored interval of the studied reservoir can be divided into two zones. Using reservoir properties such as porosity, bulk density, acoustic impedance and interval transit time indicated also two zones with an obvious variation in separation depth and zones continuity. The stratigraphic modified Lorenz (SML) plot indicated the presence of more than 9 flow units in the cored interval as well as a high degree of microscopic heterogeneity. On the other hand, principal component and cluster analyses, depending on well logging data (gamma ray, sonic, density and neutron), indicated that the whole reservoir can be divided at least into four electrofacies having a noticeable variation in reservoir quality, as correlated with the measured permeability. Furthermore, continuity or discontinuity of the reservoir zones can be determined using this analysis.

1. Introduction

Studying of the reservoir rocks has been associated with some terms such as facies, lithofacies, petrofacies, rock types, hydraulic flow units and electrofacies. The most widely used definition of facies was introduced by Reading (1978): facies should ideally be a distinctive rock which forms under certain conditions of sedimentation reflecting a particular process or environment. Lithofacies were defined by Dorfman et al. (1990) as "mappable stratigraphic units, laterally distinguishable from the adjacent intervals based upon lithologic characteristics, such as mineralogical, petrographical, and paleontological signatures that are related to the appearance, texture, or composition of the rock". Similar rock types have also been defined as geological facies or simply facies. Petrofacies are defined as intervals of rocks with similar average values in pore throat radius, thus having similar fluid flow characteristics (Porras et al., 1999). Other similar definitions have been referred to as petrophysical rock types, reservoir rock types, and static rock types. Rock type is defined as units of rock deposited under similar conditions which experienced similar diagenetic processes, resulting in a unique porosity-permeability relationship, capillary pressure profile and water saturation for a given height above free water in a reservoir (Gunter et al., 1997). This definition also indicates that rocks should be grouped according to physical properties controlling fluid storage, flow, and distribution (Rushing et al., 2008). They further differentiated rock types into depositional, petrographic and hydraulic units. The hydraulic flow unit (HFU) is defined as a mappable portion of the total reservoir, within which geological and petrophysical properties that affect the flow of fluids, are consistent and predictably different from the properties of other reservoir rock volumes (Ebanks et al., 1992). The term electrofacies was introduced by Serra and Abbott (1980) to define a set of log responses that characterizes a bed and permits it to be distinguished from the others. The aim of electrofacies

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Table 1
Statistics of the routine core data in the studied wells.

Well	No. of samples	Core permeability			Core porosity		
		Min	Max	Avg.	Min	Max	Avg.
Well A	158	0.07	1568	425.5	8	24	16.2
Well B	94	0.46	1610	198	6.8	22	16.3
Well C	80	0.07	177	13.7	1.2	17.2	9.13
Well #Ref#	514	0.01	1050	68.7	2.7	20.4	13.4

identification is to correlate them with lithofacies that are identified from core or outcrop (Doveton, 2014). Electrofacies can be used also to assign relationships for each rock type such as porosity/permeability equations (Stinco, 2006). Lee and Datta-Gupta (1999) and Perez et al. (2005) used electrofacies in predicting permeability. Kadhodaie-Ikhchi et al. (2013) integrated electrofacies and hydraulic flow unit concept to identify reservoir characterization.

In 1958, Beghtol applied a modification of variance statistical analysis to zonation of the petroleum reservoir to determine the fluid flow pattern. In order to achieve his goal, he used core permeability data for eight closely spaced wells. After four years, Testerman (1962) published his statistical reservoir zonation study. He used variance technique and core permeability data to drive zonation in four adjacent wells. The technique was based on the premises that the variation is minimized within the zones and maximized between the zones. He introduced the following four equations to prove continuity or discontinuity in the zones across the studied wells:

$$B = \frac{1}{L-1}\left[\sum_{i=1}^{L} mi\left(\overline{Ki.} - \overline{K..}\right)^2\right] \tag{1}$$

$$W = \frac{1}{N-L}\left[\sum_{i=1}^{L}\sum_{j=1}^{mi}\left(Kij - \overline{Ki}\right)^2\right] \tag{2}$$

$$R = \frac{B-W}{B} \tag{3}$$

$$\left(\overline{Khi} - \overline{Ki}\right) > \sqrt{\frac{1}{2}\left(\frac{1}{nh} + \frac{1}{ni}\right)} sz(\nu; p) \tag{4}$$

where B = the variance between zones,

L = the number of zones,

i = the summation index for the number of zones,

j = the summation index for the number of data within the zone,

mi = the number of data in the ith zone,

$\overline{Ki.}$ = the mean of the permeability data in the ith zone,

$\overline{K..}$ = the over-all mean of the data in the well,

W = the pooled variance within zones,

N = the total number of data,

the kij's = the permeability data, R = the zonation index.

$\overline{Khi}$ = the arithmetic average of the permeability data of the hth zone in one well,

$\overline{Ki.}$ = the arithmetic average of the permeability data of the ith zone in an adjoining well,

nh and n, = the number of data in the hth and ith zones,

s = the standard deviation S of all the permeability data from the reservoir,

z = a constant tabulated as a function of the number of data, the number of zones and a probability level.

v and p are used to identify z-values as functions of the probability level. Harter (1960) provided a table of z-values.

Hawkins and Merriam (1974) used gamma ray, conductivity and

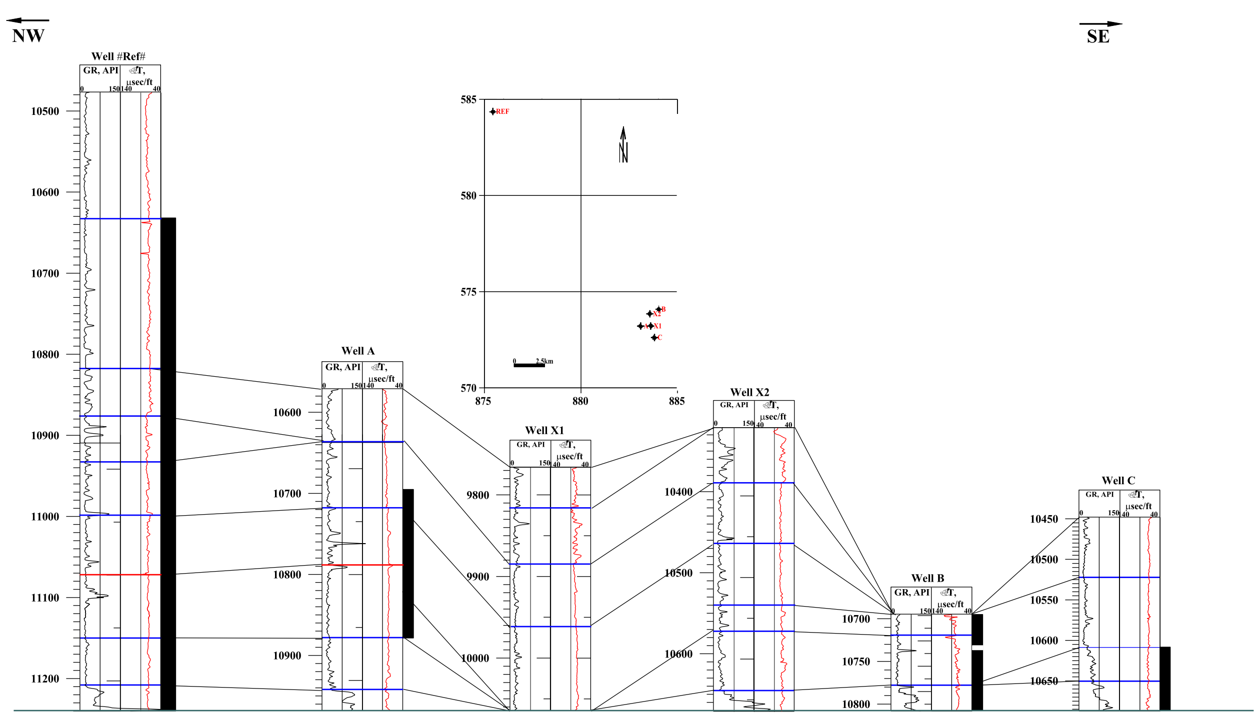

Fig. 1. Well – to – well correlation of the studied reservoir. It can be noted that the lowermost part is occurred in all wells except for well X1. Meanwhile the upper part in well # Ref# is absent in other wells. This may be attributed to non deposition.