UNIVERSITY OF SZEGED, DOCTORAL SCHOOL OF GEOSCIENCES

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INTEGRATED CHARACTERIZATION OF A LOWER-NUBIAN HYDROCARBON RESERVOIRS, WITH SPECIAL EMPHASIZE ON GEOSTATISTICAL UNCERTENTIES

THESIS OF PhD DISSERTATION

by

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INTRODUCTION

The main topic of this study to implement a geostatistical characterization of hydrocarbon bearing intervals in the Lower Nubian Formation using the integrated study of all the available data (routine core analysis, log analysis, core description, etc) from two oil fields, namely North Gialo and Farigh . However, the focus was mostly on North Gialo (6J) area, owned by Waha Oil Company.

The objective of the study is to reveal and measure uncertainties associated with reservoir heterogeneities on micro-, macro- and mega-scales by utilizing the application of geostatistics in reservoir characterization.

To meet the above objectives all cores were described in order to identify rock types building up the reservoir, interpret sedimentary structures and to identify the main depositional facies of the reservoir.

Conventional core measurements (porosity, permeability) were performed in several plug samples obtained from the available cored intervals of the subject wells. For avoiding the bias coming from non-normality of the parameters studied the average tendencies of the properties were described by using maximum-likelihood methods. The comparisons of the petrophysical characters of the identified facieses were based on some on-parametric statistical tests. Interrelations between and among core measurements by facies were also analyzed.

Well log analysis was performed on all wells penetrating the Lower Nubian sequences and located in the area studied. All the wells were quantitatively interpreted using deterministic PETROLOG approach. For selected wells having core data, log-derived porosity and permeability results were compared with core measurements, and were found to be in good agreement.

Well log correlations were performed utilizing the correlation program of PETROLOG. The Lower Nubian sequence was divided in to Lower Nubian Upper (LNU), Lower Nubian Middle (LNM) and Lower Nubian Base (LNB) subunits. In addition, these units were distributed into zones or layers.

The lateral correlation started by defining the main electro-facies by comparing well log shapes and sedimentological core descriptions. Then lateral extensions of the different well log shapes (electro-facieses) were traced. Resistivity and gamma ray curves gave excellent correlation markers.

The results of the stratigraphic and structural interpretation coming from log correlations, quantitative log interpretations and lithological core information for individual wells formed the inputs into 3D geological modeling of RockWorks software. 3D geological model was established for the study area comprising 3 reservoir unites (total of 14 layers). Results of 3D modeling are depicted in cross sections, and maps showing the distribution of gross thickness.

The results of petrophysical log analysis were then stochastically modeled using Sequential Gaussian Simulation of the individual well log properties. For the sake of uncertainties E-type estimations were performed. They provide surfaces of probability intervals belonging to each grid-points. Finally, uncertainties were measured for each of the modeled properties.

METHODS

The observed reservoir architectural elements (facies) were based on cores with roughly 1000ft of total length which were taken from five wells. They were quantitatively characterized using tools of different conventional and indicator approaches to achieve their most important geological characteristics: grain size, (clay, silt and sand content), sedimentary structures and thickness. Furthermore, their petrophysical characteristics have been measured on core plugs and estimated from well logs.

Stratigraphic framework was built by using specific marker layers, which could be observed and picked, from well-log correlation. The Lower Nubian sequence was divided into several flow unites, and petrophysical zones. This was carried out in three steps. It started in those areas where, the top and bottom of the Lower Nubian was able to pick easily by correlating the gamma ray and resistivity logs. Then the flow unites and barriers were be able to recognize. Their tops were picked by using the separation distances from both the density neutron and thorium potassium logs overlays. Finally each flow unite was divided into petrophysical zones. All the picked tops were inserted into the Rock Work software data base, and a 3D onlap stratigraphic model was constructed. Consistency of the used tops was examined.

Porosity/permeability relationship was studied via; several semi-log scatter plots of porosity versus permeability. The samples were coded by lithology, grain-size, and facies. All of them were provided by core descriptions. The influence of pore geometry factor was determined by the approach of global hydraulic element. In this way the reservoir rocks were distributed into petro-types (hydraulic unites). This analysis was performed in several steps. First was calculation of the reservoir quality indicator (RQI). Then came the determination of normalized porosity and the finally step was the definition of flow zone indicator (FZI). The processed interval is distributed into hydraulic unites according to the boundaries determined by global hydraulic element (GHE)

The quantitative well log analysis performed by utilizing all the available information from the eleven wells of North Gialo oil field and seven wells from Farigh oil field (wire line logs, core Data). The tool was a deterministic quantitative analysis of Petrolog. The scope of this work consisted of carrying out interpretations in the reservoirs to determine the rock composition: effective porosity, volumetric shale and sand fraction, to establish net thickness and the mean effective porosities and permeabilities corresponding to selected cut-off.

The geostatistical analysis of the spatial uncertainty of the petrophysical properties was achieved by generating 200 equally probable realizations using sGs approach. The simulation domain, laterally covers the study area, consisted of 28 well averaged porosities, permeabilities and shale fraction volumes. These averages were derived from quantitative well log analysis and related to the Lower Nubian net thickness. Since the frequency distributions were quite far from normality, normal score transformations were performed for each data-set. The experimental semivariograms of the transformed data were calculated in several directions. This process ended by selecting the three most characteristics directional semivariograms. They were approximated by nested theoretical models in the framework of VarioWin. During the numerical approaches we tried to reach the minimum values of Indicative Goodness of Fit. The models were accepted when their variogram surfaces were like that of normal scores. Accordingly the Sequential Gaussian Simulation was performed on 10 m of grid resolution. For the analysis of uncertainty 200 stochastic realizations were generated. E-type grids show the most probable lateral distributions of the reservoir properties. The upper and lower confidence surfaces (on p=0.1 level of significance) are formed by the boundary of probability interval containing the point-wise E-type estimations. The thickness of this interval reflected the level of uncertainty at a particular location.

THESIS

1. I have proven that the studied Lower Nubian rock body has a high degree of variability throughout the reservoir section. I have revealed those primary (depositional) and secondary (diagenetic) factors, which had an effect on reservoir quality. I have pointed out, that the entire stratigraphic section has undergone pervasive diagenetic modifications to porosity and permeability.
2. I have revealed that there is no any direct correlation between depositional facieses and core porosities and permeabilities. I have shown, that majority of the Lower Nubian has been formed in braided fluvial channel environment. As a consequence, porosity-permeability trends display an extremely high degree of variability.

3. I have concluded that roughly 78% of the total flow comes from GHE (4, 5, 6), which provides only 30% of the storage. Whereas 22% of the total flow comes from GHE (2, 3), which provides (70%) of the storage capacity. Also, the porosity-permeability trends display good clustering, if they are GHE coded.
4. The observed cores do not exhibit any abundance of open fractures. I have pointed out, that most of the fractures are closed, since they have been filled by quartz and/or clay-minerals. I have proved this by core measurements and quantitative log interpretations, too. Although production tests and DST indicated the same observation, the proving data sets are very limited.
5. In my results, the LNM has high GR and low resistivity levels. The highest shaliness content was observed from quantitative lithology evaluation (sand shale fractions). This unit is of typically sandwich-like development where sandstone and shale laminae change each other. The petrophysical properties of sandstones are controlled by poorly sorted and variable grain size distributions.
6. I have proved that the LNU sequence comprises of potentially good reservoirs. They can be characterized only on the basis of their porosity and permeability. In that way LNU3, LNU2, and LNU1 are good, LNU6, LNU5 and LNU4 are weaker, while LNU8, LNU7, and LNU9 are poor layers.
7. I have pointed out that LNU sequence can be studied on the basis of petro-type approach (Global Hydraulic Elements, GEH). I have mapped the GHE variation against the observed facieses and results of log

interpretation. The LNU3, LNU2 and LNU1 sections are dominated by GHE 3, 4 and 5. This is characteristic of moderate reservoir quality.

8. I have related the estimation of uncertainties to geological controls of heterogeneities. I have revealed that these controls, such as sedimentary facieses, diagenetic trace prints, and thickness variations can provide proper descriptions of uncertainties. I have found that these results are very close to the natural phenomenon of petrophysical properties.
9. I have declared, that the regions of high uncertainty of the E-type estimations of permeability and shale volume appear mostly in three locations of the study area. They can be recognized on the basis of the highest parameter-fluctuations. This indicates that the effect of higher uncertainty in permabilities is masked by the high uncertainty in shale fraction.
10. I have related uncertainties associated with the reservoir properties to the small scale heterogeneities of the reservoir rocks. The different uncertainties of reservoir rock properties, namely porosity, permeability and shale fraction, can be used together to study the reservoir quality controls around the wells, and even up to certain distances apart from the wells

PUBLICATIONS in PROFESSIONAL JOURNALS

1. **Sliman, O.** and Burgig, K., **2011**: Fractured Reservoir Characterization: Integration of well Logs and Geological Data, Libyan Petroleum Research Journal (in press)
2. **Sliman, O.** and Geiger, J. **2011,:** Measuring spatial uncertainty in Lower Nubian reservoirs, Lybia, Acta Mineralogica and Petrographica (in press)
3. **Sliman, O.** and Kelemen, Z**. 2000:** The Role of Principal Component Analysis (PCA) in the delineation of Lithofacies based on well logs First Symposium on Well Log Analysis and Formation Evaluation (WLA&FE) , Libyan Petroleum Research Journal, Vol 13(1431) pp.134-146.

CONFERENCE ABSTRACTS

1. **Sliman, O.** and Mousa, N., 2010: Reservoir Heterogeneity Qualification and Quantification from Macro and Mega Scales 5th Technology of Oil and Gas Forum (TOG2010), 12-14 October 2010, Tripoli-Libya.
2. **Sliman, O.** and Lalah, M., 2010: Uncertainties Related to Core Measured and Log Derived Petrophysical Properties 5th Technology of Oil and Gas Forum (TOG2010), 12-14 October 2010, Tripoli-Libya.
3. **Sliman, O.** and Burgig, K, 2004: Integrated depositional environments characterization of the Nubian sandstone reservoirs, Southeast Sirt Basin, Libya, the 8TH International Conference of Jordanian Geologists Association, April 6-7, 2004, Amman-Jordan.
4. **Sliman, O.** and Mousa, N., 2004: Identification and quantification of the uncertainty of lithology determination from well log analysis, the Seventh International Conference on the Geology of the Arab World, 16-19 February 2004, Cairo University-Geology Department.

5. **Sliman, O.** and Burgig, K., 2003: Fractured Reservoir Characterization: Integration of well Logs and Geological Data, The Second International Symposium on Improved Oil Recovery in Libya, September 16-18, 2003, Tripoli-Libya.
6. **Sliman, O.**, 2003: Sand bodies potential reservoirs identification and characterization of Paleozoic rocks in Ghadames Basin of Libya using well log analysis, VIII Symposium on Geomathematical applications, May 05-06, 2003, Szeged- Hungary.
7. **Sliman, O.** , 1999: Lithofacies analysis in Ghadames Basin made from two well logs Sixth Mediterranean Petroleum Conference

PROJECTS REPORTS

1. Quantitative Well Log Analysis and integrated Formation Evaluation (well logs, core data, production test data) in 20 wells for the task of evaluating reservoir petrophysical properties, Sirt Basin-Libya
2. Lithofacies analysis based on well logs in 34 wells of Ghadames basin Paleozoic shaly sandstone with interbedding of carbonates, ferruginous shales and organic rich shales. Well log analysis for litholgical rock composition and fracturing determination in one borehole Waha field Fach dolomite and Zelten limestone, Sirt Basin-Libya.
3. Water saturation evaluation in Bahi bioherm carbonate borehole A73, Sirt Basin-Libya.
4. Quantitative well log analysis and formation evaluation for water prospecting and production in water producing well Cambro-Ordovician shaly- silty sandstone, Murzuk basin –Libya.

5. Quantitative Log Analysis of Paleozoic Reservoirs in three key wells for Petroleum Potential Evaluation of the Ghadamis Basin Libya, (the responsibility was well log analyst)
6. Murzuq Basin Regional Aquifer Study using borehole data, seismic data,
7. Formation evaluation study for different geological environment reservoirs (Samah, Balat, Dahra, A/F structure) in 12 wells, Sirt Basin-Libya
8. Well log analysis study for 10 wells in on-land exploration Blocks (area 86 and 102/4) in Sirt basin Libya.
9. Ghani-Zenad Simulation Study for Farrud, Gir and Facha reservoirs(the responsibility was petrophysical review of the quantitative log interpretation for 230 wells drilled in Ghani/Zenad areas, Sirt Basin-Libya)
10. Integrated Formation evaluation study for different potential reservoirs (Lower Sabi, Kalash, Tagrifet) in well(A1-NC214), Sirt Basin-Libya

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Undersigned, as a co-author, declares that (1) I know all of the thesis-points of the candidate; (2) the roll of the candidate was definite in the listed publications directly presenting the result of this dissertation. Furthermore, I state that I have not used either that part of results having been published collectively or those which are detailed in the thesis-points and in the dissertation for acquiring any scientific degree. Also, I accept I must not use them for that purpose in the future.

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