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Importance of Velocity Deviation Technique and Negative Secondary Porosity in Detection of Hydrocarbon Zones in Khasib Formation, East Baghdad Oil Field

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Abstract

The velocity deviation technique is one of the important techniques in hydrocarbon investigations, through which it is possible to identify the types and the content of rock pores. The current study aimed to demonstrate the benefit of this technique in discovering the oil sites of the Khasib formation in the East Baghdad oil field, as well as the possibility of separating the oil and gas zones by combining the velocity deviation technique with the anomalous primary porosity information that leads to negative secondary porosity. In this study, log data of three wells distributed in the study area (EB-04, EB-16, and EB-34) were used. From these data, the velocity was estimated by the sonic log, the porosity was estimated by the neutron and the density log, while the velocity deviation was determined by subtracting the velocity calculated from the density log from the sonic log velocity. The result showed that there is significant agreement between the secondary porosity values that turned positive after the oil effect was removed and the confirmed oil zones derived from the core information. Also, there was a clear correlation between velocity deviation values above -500 m/s and the permeability zone of formation, which may reflect the importance of this technique in the identification of the permeability zone. Both techniques (Velocity Deviation and log porosity analysis) can be correlated to predict the locations of gas, large-scale fractures, and unconsolidated beds in sites of high negative secondary porosity and low-velocity deviation (under -500 m/s).

Keywords: Velocity deviation; Secondary porosity; Negative porosity; Khasib Formation; East Baghdad oil field

1. Introduction

Relative to most sandstone reservoirs, estimating the petrophysical properties and understanding the dynamics of fluid flowing in carbonate reservoirs are more complicated (Jameel et al., 2020). The flow of liquids through heterogeneous carbonate reservoirs is very different from that in homogeneous sand reservoirs, where the pores system is more complex in carbonate reservoirs (Hurley, 1998), (Steven et al., 2016). The analysis of well log data is an effective method for estimating the hydrocarbon production potential (Aminzadeh and Dasgupta, 2013).

The velocity deviation technique is one of the well logging techniques through which the different types of porosity are identified (Al-Baldawi, 2020) as well as the permeability trends within the rocks

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are tracked (Flavio and Gregor, 1999). Velocity deviation log is constructed by calculating the difference between the true well velocity (which is calculated from sonic log) and the velocity inferred from the neutron-porosity or density log. Negative porosity can be defined as the porosity calculated from density logs for rock zone in which the rock density is higher than the default density of zero pores limestone (2.71gm/cc), and this also leads to negative secondary porosity values. The study of secondary porosity in limestone is very important to delineate the location of fractures and diagenesis zones (moore, 2004; Guanghai et al., 2019). The aim of the current study was to use the combining technique of velocity deviation (VD) and negative secondary porosity in separating different hydrocarbon zones in the Khasib Formation in three wells (EB-04, EB-16, and EB-34) from a set of wells drilled in the East Baghdad field (Fig.1)

Fig.1. Location map of the studied wells (modified from Aqrawi et al., 2010)

2. Site Description

According to the number of proven reserves of oil (about 8 billion barrels) East Baghdad oil field was classified as one of the super-giant oil fields. The field is located east Baghdad city and extends within the governorates of Baghdad and Salah Al-Din (Fig.1), and it is a symmetrical NW-SE anticline with a length of 65 km and a width of 11 km. The major reservoir of the field is the Khasib Formation (Al-Jawad and Kareem, 2016).

The Khasib Formation is one of the carbonate formations that have a good hydrocarbon storage due to its relatively high porosity and permeability (Al-Ameri, 2011), Since this formation constitutes one of the important reservoirs in many fields of central and southern part of Iraq, it has attracted the attention of many researchers such as (Al-Ameri & Al-Obaydi, 2011; Mahammed et al., 2020; Abdullah and Al-Shahwan, 2021). The average depth of the formation in three studied wells was about 2329m and average thickness was about 101m. In general, the formation consists of limestone and shally limestone, and it can be divided into two parts, upper and lower, where the upper part contains a higher percentage of shale (Mohammed, 2018). The age of formation is Turonian-Coniacian (Al-Ali, et al., 2020), and different diagenesis processes have greatly affected the composition of the Formation resulting different

types of secondary porosity (Al-Qayim et al., 1993). In study area the formation is topped by the Tanumah Formation while Al Kifil Formation is located uncomfortably below it.

3. Materials and Methods

In this study, data from three wells from the East Baghdad field were used (EB04, EB16, and EB34). The data were used from the available well logs are; spontaneous potential, caliper, gamma-ray (GR), density (RHOB), sonic (DT), neutron (NPHI), and resistivity logs (LLD, LLS, and MSFL). Interactive Petrophysics software (IP V4.2, 2013) has been used for correction and interpretation.

The work steps can be abbreviated as follows:

1. Description of formation and identification of lithology using different cross plots
2. Calculating the all types of porosity from log information and making the necessary corrections to them.
3. Calculating the true velocity from sonic log after converting time to velocity.
4. Applying the velocity deviation technique (VD) after calculating the velocity from the porosity information using the time average equation and then subtracting it from the true velocity.
5. Calculation of secondary porosity by subtracting the primary porosity inferred from the sonic log from total porosity.
6. Correcting the primary porosity relative to the presence of oil and gas by multiplying it by the constants of 0.9 and 0.7, respectively, then find the secondary porosity in each case.
7. Comparing between results of both VD and secondary porosity in comparing it with the different oil site which are mentioned in the geological reports of the wells.

The first steps of the work was calculating the all porosity types from porosity logs (density, neutron, and sonic logs) after make the necessary corrections using the following equations:

$$PHIT = \frac{NPHI + PHID}{2} \text{----- (1)}$$

$$PHID = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_f} \text{----- (2)}$$

$$PHIS = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \text{----- (3)}$$

$$PHI_{sec} = PHIT - PHIS \text{----- (4)}$$

Where (ρ_{ma}) is the matrix density (2.71 g/cc for limestone), (ρ_f) is fluid density (1 g/cc for freshwater, and 0.8 g/cc for oil), (ρ_{log}) is the density log reading, Δt_f is the fluid transit time in $\mu\text{sec}/\text{ft}$ (189 $\mu\text{sec}/\text{ft}$ for water), Δt is the sonic log transit time in $\mu\text{sec}/\text{ft}$, Δt_{ma} is the matrix transit time in $\mu\text{sec}/\text{ft}$ (47.5 $\mu\text{sec}/\text{ft}$ for limestone), $PHID$ is the density porosity (calculated from density log), $NPHI$ is the neutron porosity (from neutron log reading), $PHIS$ is primary porosity (derived from the sonic log), PHI_{sec} is the secondary porosity, and $PHIT$ is the neutron - density porosity (Boddy and Smith, 2009).

Some corrections were made to the well data reading before the beginning of the interpretation process, which is due to the influence of some factors on this data such as mud weight, tool diameter, and casing weight. Also, the clay minerals, measured from the density log, affect porosity. This has to be corrected and the shale impact must be subtracted by the following equation:

$$V_{sh} = 0.33 * [2^{(2 \cdot IGR)} - 1] \text{----- (5)}$$

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \text{----- (6)}$$

Where:

IGR: gamma-ray index, Vsh: shale volume, GRlog: gamma-ray reading, GRmax: maximum gamma-ray reading, GRmin: minimum gamma-ray reading.

3.1. Lithology Identification

To identify the lithology information, the three porosity logs (Sonic, Density, and Neutron log) must be combined (Dawei et al., 2016). Accordingly, three diagrams have been instructed, the first was RHOB / NPHI cross plot, the second was M-N cross plot, and the third was PHID-NPHI cross-plots. The effective porosity and shale types for the studied wells are estimated using a triangle. PHID-NPHI cross-plot.

3.2. Velocity Deviation Log (VDL)

The velocity deviation log was created by combining the true velocity log (calculated from the sonic data) with the velocity log computed from the time-average equation (Wyllie et al., 1956) as below:

$$\frac{1}{V_{rock}} = [(1 - \phi)/V_m] + [\phi/V_f] \text{ --- (7)}$$

Where: V_{rock} is the calculated velocity, ϕ is neutron porosity (NPHI) or density porosity (PHID), V_m is the velocity of the matrix (6530 m/s for limestone), and V_f is the velocity of the fluid (1500 m/s for water), (Flavio and Gregor, 1999).

The velocity deviation (VD) was calculated by the following equation:

$$VD = V_{sonic} - V_{neutron} \text{ or } V_{density} \text{ --- (8)}$$

Where: V_{sonic} , $V_{neutron}$, $V_{density}$ represent the velocity calculated from sonic, neutron, and density logs respectively. Sonic velocity is calculated from the sonic log after transforming the time data into velocity.

3.3. Secondary Porosity

Secondary porosity (PHI_{sec}) was calculated by subtracting the primary porosity (PHI_s) from the total porosity (PHI_t). PHI_s and PHI_{sec} was corrected by using the fresh mud value of $T_f = 189 \mu\text{sec}/\text{ft}$.

4. Results

4.1. Lithology Identification

From Neutron-Density plots (Fig. 2), the results show that the dominant mineral matrix in the formation is limestone with a little proportion of sand and shale. The parameters M and N are lithology-dependent so that the interpretations of density, neutron, and sonic logs are used to construct the M-N plot which benefits the lithology determination. Fig. 3 shows the M-N plot of three wells, these plots illustrate that the formation consists of limestone in all wells with a large proportion of high transit time (Δt) materials (shale, oil, or large-scale fractures) in EB04, and EB16 wells that displaced a large number of points towards the site of

Fig.2. The density-neutron (RHOB-NPHI) plot of well EB04

Fig.3. M-N crosses plots for the three studied wells

The applied Neutron-Density and M-N cross plots displayed that the dominant lithology in Khasib Formation in the studied wells is limestone with some sandstone and shale.

From the PHID-NPHI cross-plots (Fig.4) it can be seen that the most common type of shale found in the three studied wells is dispersed shale (DIS sector in plot), except some points in Well EB04 appear in the area between (laminar and structural shale types), which indicates that there are three types of shale in these wells which have a great effect on different porosity values. Effective porosity in the three wells is ranged from 10-30%.

Fig.4. PHID-NPHI cross-plots for the Khasib Formation in all studied wells

Fig.5 shows the relationship of NPHI minus PHID with gamma-ray intensity. Most of the points for this relationship in the three wells lie in the average distance between high and low porosity, indicating medium porosity with medium water saturation.

Fig.5. NPHI minus PHID vs. Gamma-ray intensity cross-plots for Khasib Formation in all studied wells

4.2. Velocity Deviation

Fig. 6 showed the velocity logs calculated from sonic and neutron logs. The increase in a shale volume leads to a significant increase in the velocity calculated from neutron porosity relative to the original velocity calculated from the sonic log. A clear difference can be observed between $V_{neutron}$ and V_{sonic} at well EB16, which indicates the possibility of a permeable region in this well.

Fig.6. The velocity logs produced from sonic and neutron logs with the shale volume for the three wells. The velocity deviation log (Fig. 7) showed that the positive deviation (blue color) zones were identified by pores within a dense, cemented matrix, where the pores are often not connected. As a consequence, a positive deviation can also imply low permeability. Deviations of +500 to -500 m/s usually occur in intercrystalline, interparticle or high microporosity zones.

In general, the positive velocity deviations are related to the increase in porosity, which usually leads to an increase in permeability, except in the case of the dominance of the unconnected microporosity, in which case the permeability decreases, on this basis, the velocity deviation technique was used to identify the permeability systems and the effect of the types of porosity on them (Flavio and Gregor, 1999). The Positive deviations in velocity (more than 500 m/s) indicate zones when velocity is more than expected from porosity values, such as zones dominated by frame-forming pore forms. Zero deviations (-500 to 500 m/s) show intervals where the rock lacks a rigid frame, such as in carbonates with high antiparticle porosity or microporosity. Three causes can create a large negative deviation in velocity

(less than -500 m/s) fractures, cavernous wall of hole, or presence of large amounts of gas, and these cases can usually be distinguished by continuously tracing downhole velocity deviation (Flavio and Gregor, 1999)..

Fig.7. VDLs for the three wells in the study area show positive values (blue), and negative values (red) with corresponding Vsh curves.

4.3. Secondary Porosity

The result showed that the corrected primary porosity (PHISc) values for the Khasib Formation are greater than the total porosity (PHIT) values at most depths in the wells (EB04, and EB16), which leads to negative secondary porosity (PHIsec) values (Fig. 8). This may occur due to saturated (water, oil, gas) or fractured zones. The porous microstructure of carbonate reservoirs is complex, as they consist of primary porosity (matrix pores) and secondary porosity (microfractures and vugs). In carbonate

deposits, the type and value of secondary porosity has a significant influence on the prediction of permeability and the estimation of hydrocarbon reserves.

The smaller the secondary porosity, the higher the primary porosity. Lower velocities and hence longer transit durations will occur from more compressible fluids, such as gas and oil (higher PHISc). abnormal increasing in the corrected primary porosity (PHISc) compared to the total porosity (PHIT) in the two wells (EB04 and EB16) could be explained by the presence of hydrocarbons or unconsolidated zones. In order to get accurate results of (PHISc) it must multiplied by the coefficient (0.7) to remove the effect of gas and by the coefficient (0.9) to remove the effect of oil. Fig. 9 shows the PHISc-PHIT cross plot, which is an indication of the type of porosity prevailing in the formation While Fig.10 shows the different PHISec curves according to PHISc corrections.

Fig.8. PHIT, PHISc, and PHISec curves for Khasib Formation in the three wells with the corresponding Vsh curve. Blue in track 4 represents the positive values of PHISec while red is the negative values

Fig.9. PHISc-PHIT cross plot for the three wells in the study area

Fig.10. Positive and negative PHIsec values (blue and red colors respectively) after reducing oil (fourth track) and gas (fifth track) effects for the three wells

5. Discussion

To get a clear idea of the locations of saturated zones in the three wells, the velocity deviation, and secondary porosity logs were combined. Besides, other log information (resistivity, porosity, gamma-ray, sp, and density logs) were used for comparison and interpretation. Also, the available core data for the three studied wells were used to delineate the locations of oil evidence. (Figs. 11, 12, and 13).

Fig.11. All available logs for well EB04. Dark blue represents the positive values of three PHIsec curves, light blue indicates VDneutron values that are more than -500 m/s, and green site is certain oil evidence derived from core data

The positive values of PHIsec (track 5) for depths (2466-2476m) approximately correspond to the values of VDneutron (track 7). This may indicate the validity of these two techniques to detect the sites of oil in this well, which are marked in green (track 8). Besides, the negative values of secondary porosity associated with the negative velocity deflection may be interpreted as unconsolidated (higher shale) or large-scale fracture zones. There is a significant decrease in the values of PHIsec at the top of

the formation due to the presence of small quantities of oil as shown in the core information (track 8) in addition to a high percentage of shale which leads to an increase in PHISc and thus a decrease in PHIsec values. From the observation of the velocity deviation curve and its correlation with the information of the resistivity logs, it is clear that there is still a percentage of the permeability below the depth of 2476m (no core data) that allows the presence of oil spots at these depths despite the presence of a significant proportion of shale at these depths (Fig. 11).

Fig.12. All available logs for well EB16. Dark blue represents the positive values of three PHIsec curves, light blue indicates VDneutron values that are more than -500 m/s, and green site is certain oil evidence derived from three core intervals (1, 2, and 3)

The oil presence sites (track 8) obtained from the core data correspond to the significant decrease in PHIsec (track 4) more than they correspond to VDneutron values greater than -500 (track 7). When the values of PHISc are multiplied by the constant 0.9 to correct them from the oil presence, a great agreement appears between PHIsec values inferred from this correction (track 5) and the oil evidence for the core intervals (2, and 3). Whereas the first core interval (1), needs to be multiplied by a larger coefficient (0.7) (track 6) to get rid of the abnormal secondary porosity values, which may indicate the presence of some gas pockets in this interval. Besides, the presence of large-scale fractures leads to a large increase in the values of PHISc and thus a decrease in PHIsec values. The values of VDneutron (track 7) match the positive values of PHIsec (track 5) more closely than the positive values in (track 6) at all core's intervals, indicating more oil than gas at these depths. In the lower parts of the formation, large fluctuations in the porosity values (track 9) are accompanied by the disturbances in the values of resistivity (track 3) indicating changes in the permeability values that were seen in the velocity deflection curve (Fig. 12).

Fig.13. All available logs for well EB34. Dark blue represents the positive values of three PHIs_{sec} curves, light blue

indicates VDneutron values that are more than -500 m/s, and green site is certain oil evidence derived from core analyses

The increase in PHIs_{sec} values of Khasib Formation in this well may be attributed to the decrease in its depth, which is less than the other studied wells by (100-200 m). Its location in the north of the field, surrounded by several active faults, may also have an important reason for increasing its PHIs_{sec} values. The decrease in PHIs_c values of this formation in this well is the direct reason for increasing its PHIs_{sec} values. The increase in the values of (VDneutron) over -500 shows the permeability sites in this well (almost all depths), which is clearly shown by the separation between the resistivity logs (track 3). The oil spots at the bottom of the formation (track 8) are consistent with the large variation in the values of PHIs_{sec} and VDneutron (tracks 3, 4, 5, and 6) at these depths, which supports the validity of these techniques in detecting oil sites in the petroleum reservoirs. The large decrease in VDneutron values (track 7) at the depth (2286 m) results from a very high increase in shale volume (track 2) at this depth.

6. Conclusions

There is a good match between the negative secondary porosity, which became positive after removing the oil effect from it, with the oil evidence obtained from the core information. This match

confirms the validity of this technique in detecting the oil accumulation zones in the formation. Besides, the great agreement between velocity deviation values greater than -500 and the clear separation of the resistivity logs indicates the importance of the velocity deviation technique in detecting the permeability zones in the formation. Both techniques can be correlated to predict the locations of gas, large-scale fractures, and unconsolidated beds in sites of high negative secondary porosity and low-velocity deviation under -500m/s. In comparison with the other studied wells, the apparent increase in the secondary porosity of the well EB34 located in the north of the field may indicate that the well site was affected by faults and the surrounding tectonic activity, which explains the higher positive values of velocity deviation in this well.

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