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Lithological Study of Mishrif, Rumaila, Ahmadi and Mauddud Formations Using Vp/ Vs Ratio, Acoustic Impedance and Well Logging at Amara Oil Field, Southern Iraq

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Abstract

The lithology of four formations from the Cretaceous period (Mishrif, Rumaila, Ahmadi, and Mauddud) was evaluated using the Acoustic Impedance and Vp/Vs ratio cross plot from Rock Physics Templates. Dipole sonic logs in Am-6-Am-10 well log were used to calculate compression velocity then the estimated shear velocity using Greenberg Castagna equations. RHOB and VP logs were used to calculate Acoustic Impedance. The ratio of Vp/Vs was measured then used with Acoustic Impedance colored by shale volume which is measured from gamma ray log, porosity and water saturation to estimate lithology type of the considered formations using cross plots and rock physics chart in the Techlog software. The lithology of the formations found to be of high porosity limestone alternating with hard limestone layers and the shale volume increases in the Ahmadi formation. The water bearing zone was found in all Formations, this zone is indicted by high Vp/ Vs ratio and low AI. The hydrocarbon bearing zones were indicated by low amount of both Acoustic Impedance and Vp/Vs ratio and this observation was shown in Mishrif and Mauddud formations.

Keywords: Middle Cretaceous; Vp/Vs Ratio; Acoustic impedance; Amara Oil Field; Southern Iraq

1. Introduction

The Amara oil field is located within the unstable shelf within the zone of the Mesopotamian basin near the northeastern slope of the Arab-African platform (Fouad, 2010, Al-Banna and Ali, 2018). This field is considered as one of the small fields located in the region, such as Al-Rafidain, Ali-Al-Sharqi, Kumait, Dujaila and Al-Rifai (Khanawi et al., 2010). This field represents an anticline structure, which was discovered for the first time by seismic exploration survey at 1958. The seismic reinterperation indicated that the anticline axis of Amara oil field trends from NW-SE (M.O.C, 2011). The length of top Mishrif structure in Amara oil field is 18km and its width is 4.5 km with enclosure of about 80 m (FGR Am-6 well). The combination of compression velocity Vp, shear velocity Vs and bulk density are used to determine elastic constants (Colin et al., 1997), while the Vp/Vs ratio gives additional information about lithology (Nassir et al., 2020). The Shear velocity (Vs) is one of important physical properties, which is calculated normally from shear sonic log “shear interval transit time “, but the Vs have not been recorded for the old wells due to the lack of logging equipment or limited funds (Wang,

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2019). There are many studies discussed the determination of Vs from VP depending on rock physics and statistical empirical regressions equations. In this study the equations of Greenberg and Castagna, (1992) will be used to calculate Vs from Vp at Am-6 and Am-10 wells from Amara oil field for four carbonate formations from middle Cretaceous period. These formations are Mishrif, Rumiala, Ahmadi and Maaddud; these formations are different in lithology, the percentage of minerals and petrophysical properties that effect density and velocity logs deflection. Acoustic impedance is a physical property of the rocks and it depends on lithology type, porosity percentage, fluid saturation and other factors (Latimer et al., 2000; Awadh et al., 2018; Al-Mimar et al., 2018). Many studies were done using well log data in multiple results, (Al-Baldawi, 2020) determined the pore type and porosity trend by convert sonic and neutron porosity or density porosity to velocity deviation log using means of time average equations in Mishrif Formation taking data from two wells in Halfaya oil field. (Mohammed et al., 2020) produced and compared the missing neutron, density and deep resistivity logs together using the Artificial Neural Network ANN in Petrel software. of the Early Cretaceous Nahr Umr Sandstone and the Late Cretaceous Mishrif formations of the well Noor- 10.

2. Locations of the Study Area

Amara oil field lies on Messan at distance 20km east of Al Rafidden structure and 20km south east Kumait structure (Fig.1) (IPEC, 2010). Table 1 shows the coordinates of studied wells.

Table 1. The coordinates of Am-6 and Am-10 wells

Well	E	N	RTKB Elevation(m)	Ground Elevation(m)
Am-6	699 045	351 8582	14.4	5.8
Am-10	697 150	351 9250	14.4	5.6

Fig.1. The Amara oil field map (Sadooni, 2004), the wells location (adapted from M.O.C. Maps)

3. The Geology of Amara Oil Field

The surface of the study area is covered with sediments of the Quaternary period (Pleistocene and Modern Era), which consist of fine sand, clay and gravel (IPEC, 2010). The stratigraphic section in the

field was identified and the formation depths were determined see Table 2 and Fig.2, while a comparison between the thicknesses of the geological formations was made.

Table 2. The top of the formations at studied wells (Am-6, and Am-10)

Formation	Top (m) well, Am6	Top(m) well, Am10
Mishrif	2864.5	2874
Rumiala	3270	3272
Ahmadi	3285	3284
Mauddud	3311	3309

Fig. 2. The composite stratigraphic column of the southern region, Iraq (Mohammed, 2018)

According to the previous studies and final geological reports (M.O.C., 2015) for the two wells Am-6 and Am-10, the studied formation consists of the following:

3.1 Mishrif Formation

Which is composed mainly of many types of limestone (porous, compact and chalky limestones) with shale layers. The Mishrif Formation from middle Cretaceous late Cenomanian, the thickness of the Mishrif Formation in Amara oil field almost more than ≈ 400 m in total and it forms eight sub units with barriers between them. (Al-Baldawi, 2015)

3.2 Rumaila Formation

From M. Cretaceous to M. Cenomanian, with low thickness ≈ 14 m in total, it is composed of compact limestone only.

3.3 Ahmadi Formation

From M. Cretaceous to M. Cenomanian, with low thickness ≈ 26 m in total, it is composed of compact limestone and high shale volume. (Aqrabi et al., 2010).

3.4 Mauddud Formation

From Cretaceous to E. Cenomanian age and it is composed of porous limestone, chalky limestone and compact limestone with shale, formation thickness $\approx 225\text{m}$ in total. (IPEC, 2010).

4. Materials and Methods

The work procedures which are used to achieve the results pass through many steps: at the beginning the available log data were loaded and processed by applying environmental correction for hole size, pressure and temperature to the bulk density, neutron porosity, gamma ray and resistivity data, then the shale volume was calculated from corrected gamma ray log which is used as lithology identification tool, NPHI was read directly from the field and represented the neutron porosity that depends on the fluid amount in the pores and the percentage of hydrogen concentration, RHOB is a bulk density log that reflects the density of matrix and saturated fluid density while the Neutron-Density porosity (effective and total) were determined using neutron and bulk density logs, water saturation was calculated using Archie's equation after having the water resistivity from salinity method and a , n and m parameters from Pickett plot (Asquith, 2004). These logs data were used to evaluate the lithology type with depth connected with crossplot of AI & Vp/Vs. Lithology type according to the differentiation between logs curves are used to evaluate the lithology of formations using Density and NPHI logs to draw crossplot between RHOB-NPHI. The Vp was calculated from Dt (interval transit time log) and then Green Castagna, 1992 equation was used to calculate Vs from Vp, this method uses many equations (1, 2 and 3) for each lithology type and depends on Vp data.

$$\text{For limestone} \quad V_s = -0.05508V_p^2 + 1.01677V_p - 1.03049 \quad (1)$$

$$\text{For sandstones} \quad V_s = 0.8042 V_p - 855.88 \quad (2)$$

$$\text{For shale} \quad V_s = 0.76969V_p - 867.35 \quad (3)$$

The fluid mixing rock model was used to evaluate fluid density distributed with depth for each formation using the petrophysical parameters as input especially water saturation log, the estimated fluid density log was used to evaluate our final result. According to the relation between bulk density and velocity with rock physics that depends on lithology type, fluid type, porosity percentage and fluid saturation the formation can be evaluated and hydrocarbon depths can be determined (Hami-Eddine et al., 2015). Acoustic impedance and the ratio between Vp/Vs were used to determine lithology and fluid types, where the decrease in AI value and the Vp/Vs ratio indicate the presence of hydrocarbon fluid, while the increase in AI with the decrease in the VP/VS ratio reflects the increase in cement value, and the decrease of AI with increase in Vp/Vs indicates porosity with water saturation (Avseth et al., 2006). The Vp/Vs, AI crossplots were drawn and colored with shale volume, effective porosity, total porosity and water saturation to evaluate formations lithology type and fluid type with depth.

5. Results and discussion

The lithology of four formations is evaluated using Schlumberger, 2005-2010-RHOB, NPHI crossplot. Figs 3, 4, 5 and 6 reflect the result from RHOB, NPHI crossplot for each formation in the two wells. Mishrif, Rumiala, Ahmadi and Mauddud formations points were distributed around limestone line represent the main lithology is limestone with some points cluster near dolomite line represent the exist of dolomite in thin depths of Mishrif of Am10 well, Ahmadi and Mauddud either. The points that clustered near sandstone line may occur either as results of exist some deposits from chemical Chert minerals or as result to increase shale volume in this point. The formations known as not homogeneous and it contain many things affect the crossplot result.

Fig. 3. Mishrif, Formation lithology crossplot from using NPHI with RHOB logs a) In Am-6, b) Am-10 wells of Amara oil field

Fig.4. Rumaila Formation lithology crossplot from using NPHI with RHOB logs a) In Am-6, b) Am-10 wells of Amara oil field

Fig. 5. Ahmadi Formation lithology crossplot from using NPHI with RHOB logs, a) In Am-6, b) Am-10 wells of Amara oil field

Fig. 6. Maaddud Formation lithology crossplot from using NPHI with RHOB logs a) In Am-6, b) Am-10

Figs 7, 8, 9 and 10 show the relationship between Acoustic impedance on the x axes and Vp/Vs ratio on the Y axes. Each figure has five plots for each well, the first plot shows the distribution points colored by shale volume, the second plot colored by ND total porosity, third plot colored by ND effective porosity, and forth plot colored by water saturation and the final plot represents the formation points colored according to the interpretation of the formations. The percentages of AI, Vsh, EPHI, TPHI, Sw and Vp/Vs for the whole formations were discussed below. Figs.7, 8, 9, 10 and 11) show three clusters of colored points, the blue points represent depths with low shale volume, low TPHI, EPHI and high Sw. The AI ranges 13500 to 16811. g.m/cm³.s and Vp/Vs 1.79 to 1.93. The lithology of this formation is limestone with high water saturation as fluid type.

The green points represent depths with increasing TPHI and EPHI and decreasing the Sw and that lead to AI ranges from 9000 to 13000 g.m/cm³.s and This part reflect porous limestone with water as fluid. The light green points have range of AI from 6800 to approximately 11000 g.m/cm³.s and Vp/Vs from 1.71 to 2 it represents high porosity and low water saturation depths with low density, the oil exist at point with low AI and Vp/Vs and it depends on the oil and water volume percentage. The Mishrif Formation at well-10 is the same, with two colored areas the blue and green points. Fig.12, 13, 14, 15 and 16) show two colored points clustered in Am-6, the blue points distributed along limestone line with low value of Vsh and TPHI, EPHI and high Sw, AI range from 13000 to 15600 g.m/cm³.s with Vp/Vs range between 1.79- 1.8, while the green point area represents depths with low SW and high porosity little than Am-10 so the lithology is limestone with low porosity and high water saturation as fluid type. For Am-10 AI range between 13000-15438 g.m/cm³.s and Vp/Vs range between 1.8-1.9 and it indicates low porosity limestone with water fluid.

Fig. 7. The acoustic impedance versus the Vp/Vs ratio colored by shale volume for the Mishrif Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 8. The acoustic impedance versus the Vp/Vs ratio colored by effective porosity for the Mishrif Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 9. The acoustic impedance versus the Vp/Vs ratio colored by water saturation for the Mishrif Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 10. The acoustic impedance versus the Vp/Vs ratio colored by total porosity for the Mishrif Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 11. Interpretation colored according to the value of the acoustic impedance versus the Vp/Vs ratio for the Mishrif Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 12. The acoustic impedance versus the Vp/Vs ratio colored by shale volume for the Rumaila Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 13. the acoustic impedance versus the Vp/Vs ratio colored by effective porosity for the Rumaila Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 14. The acoustic impedance versus the Vp/Vs ratio colored by water saturation for the Rumaila Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 15. The acoustic impedance versus the Vp/Vs ratio colored by total porosity for Rumaila Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 16. Interpretation colored according to the value of the acoustic impedance versus the Vp/Vs ratio for the Rumaila Formation in Amara oil field a) at Am-6 b) at Am-10

In Figs.17, 18, 19, 20 and 21, the points colored by blue have AI ranges between 11000 - 17100 and Vp/Vs ranges between 1.74 to 1.9 at Am-6 and AI ranges between 11000 - 14800 and Vp/Vs ranges between 1.73-1.9 at Am-10 and it represent the low porosity, low Vsh and high-water saturation representing low porosity limestone depths with water fluid. The green points reflect higher Vsh, EPHI, and TPHI and lower Sw than blue area, the AI ranges between 6100 - 13000 and Vp/Vs ranges between 1.71 to 2.17 at Am-6 and AI ranges between 7537 – 13000 and Vp/Vs ranges between 1.73-1.97 at Am-10. It represents pores limestone with high shale volume and water saturation fluid. Figs. 22, 23, 24, 25 and 26 show the Maaddud formation distribution points in the AI & Vp/Vs cross plot, the formation points are classified to blue area points which reflect AI range between 14000 - 17100 and Vp/Vs range between 1.72 to 1.94 at Am-6 and AI range between 13000 – 16300 and Vp/Vs range between 1.78-1.97 at Am-10 and it represent the low porosity, low Vsh and low Vsh, TPHI, EPHI and high Sw that means low porosity limestone with water fluid type.

The green points reflect higher EPHI, and TPHI and lower Sw than blue area, the AI ranges between 10000 - 13000 and Vp/Vs ranges between 1.8 to 1.9 at Am-6 and AI ranges between 10000 - 13000 and Vp/Vs ranges between 1.78-1.94 at Am-10. It represents pores limestone with high shale volume and water saturation fluid. The light green points have lower acoustic impedance and range of Vp/Vs from low to high, this area reflects points with high porosity and low Sw, the points with low AI and low Vp/Vs indicates oil fluid found in pores.

Fig. 17. The acoustic impedance versus the Vp/Vs ratio colored by shale volume for the Ahmadi Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 18. The acoustic impedance versus the Vp/Vs ratio colored by effective porosity for the Ahmadi Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 19. The acoustic impedance versus the Vp/Vs ratio colored by water saturation for the Ahmadi Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 20. The acoustic impedance versus the Vp/Vs ratio colored by total porosity for Ahmadi Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 21. Interpretation colored according to the value of The Acoustic Impedance versus the Vp/Vs ratio for the Ahmadi Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 22. The acoustic impedance versus the Vp/Vs ratio colored by shale volume for the Maaddud Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 23. The acoustic impedance versus the Vp/Vs ratio colored by effective porosity for the Maaddud Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 24. The acoustic impedance versus the Vp/Vs ratio colored by water saturation for the Maaddud Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 25. The acoustic impedance versus the Vp/Vs ratio colored by total porosity for the Maaddud Formation in Amara oil field a) at Am-6 b) at Am-10

Fig. 26. Interpretation colored according to the value of the acoustic impedance versus the Vp/Vs ratio for the Maaddud Formation in Amara oil field a) at Am-6 b) at Am-10

6. The Final Interpretation of Log

In Figs. 27 and 28 the corrected for hole size bulk density, the velocity ratio, compressional and shear velocities, Acoustic impedance fluid density, total, effective porosity and shale volume (this Vsh log calculated using GR log) logs were drawn as a final interpretation image. These images colored with depth (green and blue) according to the interpretation-colored zones that have been discussed above for each formation. The low-density depths with low velocity and AI with green color represent high porosity limestone with high Vsh low densities rocks and range of Sw. The blue depths represent high bulk density and low porosity high AI, Vp, Vs and high water saturation in this low porosity and it indicates low porosity limestone. From these final images we notice that Mishrif Formation contain of almost nine zones of high porosity total and effective separated by six hard zones represented in blue area with high water saturation, Rumiala Formation have low thickness consist of only hard limestone with very low porosity and high-water saturation. Ahmadi Formation has high shale volume limestone with high total porosity low effective porosity and high-water saturation. Maaddud Formation has two main zones of pores limestone with range of water saturation represented by green color and separated by hard limestone layers with high water saturation in blue color.

Fig. 27. The interpretation logs of Am-10 well in Amara oil field, Southern Iraq

Fig. 28. The interpretation logs of Am-6 well in Amara oil field, Southern Iraq

7. Conclusions

The use of rock physics crossplot between AI and Vp/Vs ratio to evaluate lithology, fluid type at Amara oil field. The data were taken from two wells Am-6 and Am-10. The results show that Mishrif, Rumaila, Ahmady and Mauddud formations are mainly composed of limestone (high porosity limestone separated by low porosity limestone). The Mishrif Formation contains of almost nine zones of high porosity total and effective separated by six hard zones represented in blue area with high water saturation, the Rumaila Formation have low thickness consist of only hard limestone with very low porosity and high-water saturation. The Ahmadi Formation has high shale volume limestone with high total porosity low effective porosity and high-water saturation. The Mauddud Formation has two main zones of pores limestone with range of water saturation represented by green color and separated by hard limestone layers with high water saturation in blue color, this formation end by non-pores limestone layer. The zone with high Vp/Vs and high AI indicates water fluid within low porosity rocks and that exists in all formation represented in blue color. The low amount of both AI and Vp/Vs ratio indicates zone of hydrocarbon fluid and that exists in Mishrif and Mauddud formations represented in green colored.

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