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Study of Rock Types and Diagenetic Facies based on Velocity Deviation Log for Unraveling the Reservoir Heterogeneity in a Mixed Siliciclastic-Carbonate Reservoir, Southwest of Iran

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Abstract
Investigating depositional and diagenetic factors that control pore systems properties of reservoir rocks is essential for unraveling reservoir heterogeneity and interpreting reservoir rock types. In this respect, utilization of petrophysical well logs provides enormous information about reservoir properties, which can be interpreted continuously throughout the reservoir interval. In this study, the velocity deviation log derived from the Wyllie time-average equation has been used to differentiate reservoir rock types of the Oligo-Miocene Asmari Formation with a mixed siliciclastic-carbonate lithology from the field in the southwestern of Iran. As a result, four rock types were identified and interpreted throughout the reservoir interval. Each carbonate rock type with certain pore types and reservoir property signifies a specific diagenetic facies. Variation from a siliciclastic (sandstone-shale) environment in lower parts of the reservoir interval to a carbonate system in upper parts, as well as a transition interval (interlayers of carbonate and clastic facies) between them, shows a high degree of reservoir heterogeneity. This could be described by different zones and interpreted in the framework of sequence stratigraphy. The results indicated that the carbonates due to the complex pore systems have the main control on vertical reservoir heterogeneity, reflected by wide variations in velocity deviation. However, the sandstones control the horizontal reservoir heterogeneity through the variability in thickness and lateral continuity of reservoir zones. The findings of this research can be correlated with dynamic reservoir data for the identification and investigation of production zones in the field.

Keywords: Reservoir Heterogeneity, Pore System, Diagenesis, Reservoir Rock Types, Velocity Deviation Log.

Introduction
Reservoir rocks, under the effect of pore system properties, show wide variations in reservoir characteristics. Pore systems of reservoir rocks, including pore spaces and pore throats, play an important role in fluid flow and trapping in the reservoir [1]. Carbonate reservoirs, in most cases, show inherent heterogeneity [2]. The reservoir heterogeneity, described as a variation of reservoir properties with space [3], affects petrophysical log responses (e.g., resistivity and sonic logs) and derived petrophysical parameters, including porosity, saturation and permeability [4]. Textural and diagenetic characteristics of carbonate rocks have significant control on reservoir heterogeneity and quantitative and qualitative properties of their pore systems [5-9]. Heterogeneity covers a wide range of scales, from micro-scales related to pore systems to mega- and giga-scales related to sedimentary elements (sedimentary units and structures) and structural features (fractures and faults). Therefore, depending on the study scale, different methods and techniques, including core description and analysis, thin section observation, well log analysis, and seismic interpretation, have been developed to unravel reservoir heterogeneity. Investigation of reservoir pore systems using various methods and tools is one of the issues that have been considered by many researchers [10-14]. In this regard, carbonate reservoirs have more complex pore systems than sandstone reservoirs due to the facies diversity and especially the effect of diagenetic processes [15]. The effect of these processes on reservoir rocks is so significant that the prediction of reservoir properties purely based on depositional facies be unreliable and even impossible. Therefore, providing effective methods and techniques for investigating the pore types of reservoir rocks and reservoir rock typing have a significant role in reservoir characterization. In addition, the application of these methods varies according to available data and study objectives. In this

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respect, petrophysical logs, due to the availability almost in all wells of the field, and their continuity covering the entire reservoir interval, are in priority for reservoir study targets, especially when they are compared with core data that are expensive and limited to a few wells of the field and certain sections of the reservoir. Utilizing well log data and quantitative petrophysical interpretations are also common in the qualitative description of reservoir rocks. Porosity as an indication of reservoir quality is the main petrophysical parameter that can be estimated from petrophysical logs, including neutron, density and sonic. Porosity determination using the sonic velocity was introduced by Wylie et al. in [16-18], and then in their studies, it was considered by other researchers [19, 20]. Some researchers also explored the pore structure and geometry relationship with sonic velocity and reservoir quality [21, 22]. The velocity deviation log was first introduced and used by Anselmetti and Eberli in 1999 [23] to interpret pore types and their associated diagenetic features in carbonate reservoirs. This log that is obtained from the integration of porosity logs (neutron, density, and sonic) according to the Wyllie time-average equation [16] has been recently considered as a useful tool contributing to the study of pore systems properties and heterogeneity analysis of reservoir rocks [24-28]. Therefore, in this research, it was considered by focusing on the Oligo-Miocene Asmari Formation in a field located in Dezful Embayment of the Zagros area, southwest of Iran, as seen in Figure 1a. Due to the reservoir importance of the Asmari Formation and its significant development in southwestern Iran, this formation has been the target of many researchers in this area [29-33].

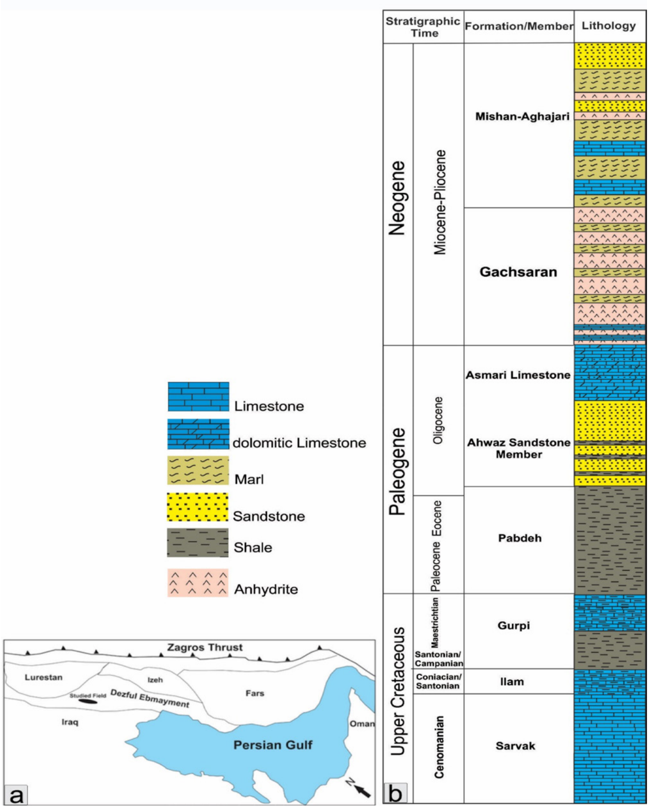

Fig. 1 a) Schematic map showing the structural features of the Zagros Basin, southwest of Iran (modified after [36]). The location of the studied field is shown in Dezful Embayment. b) Stratigraphic column of the studied field.

The study field has an asymmetric anticline structure with 27.5 km length and 7.5 km width and a northwest-southeast trend. The stratigraphic succession in drilled wells of the field includes the upper Cretaceous Sarvak Formation to Miocene-Pliocene Aghajari Formation, as seen in Figure 1b. The lower boundary of the Asmari Formation with shale/marl units of the Pabdeh Formation and upper boundary with evaporites of the Gachsaran Formation are continuous and conformable. The Asmari Formation in this field is divided into 6 reservoir zones (Z1 to Z6), based on lithology and petrophysical well log responses.

The Asmari Formation in the studied field has a mixed carbonate-siliciclastic lithology. The clastic section of the formation is, in fact, tongues of the Ahwaz Member with sandstone and shale lithology. The carbonate section, which forms the upper parts of the formation, consists of limestone, dolomite, and thin interlayers of shale and anhydrite, ending with Gachsaran evaporites as a cap-rock. A homoclinal carbonate ramp platform with occasional terrigenous input to the basin has been proposed for the mixed carbonate-siliciclastic interval of the Asmari Formation in other fields [34,35].

To unravel the reservoir heterogeneity, the reservoir rocks were first described based on their depositional and diagenetic characteristics. Afterwards, reservoir facies were investigated based on core porosity and permeability data. Finally, the velocity deviation log was extracted and used for the identification of reservoir rock types. As variations in values of this log were attributed to the depositional and diagenetic characteristics and pore systems properties of the reservoir rocks, which based on reservoir rock types and diagenetic facies were introduced.

Materials and Methods

In this study, log data from three wells of the field in combination with core porosity and permeability data available from one well were used. After processing, well log data, including neutron, density, and sonic, and required corrections (log tension, bad hole flags, etc.) were utilized. At the first step, reservoir facies and diagenetic features of the reservoir interval were described, as the results have been summarized in Table 1. Then, the velocity deviation log was extracted by using the porosity logs (DT, NPHI, and RHOB), based on the Wyllie equation (1956). The basis and stages of the study are described in below.

The conversion of the sonic log to porosity by using the Wyllie equation is used as a common method for determining the sonic porosity [37-39]. The comparison of the porosity values obtained from the sonic log with the values obtained from neutron and density logs shows a difference, which is attributed to the secondary porosity related to diagenesis. In general, there is an inverse relationship between porosity and wave velocity. But significant deviations from this relationship were attributed to certain pores types by Anselmetti and Eberli in 1999. According to their study results, positive deviation values show zones with isolated pores (moldic and intrafossil) within the rock framework. Deviations close to zero show intervals with interparticle pores and micropores. Negative values can also be due to washouts, fractures, or high content of free gas. Based on the Wyllie equation, the velocity of elastic waves in a rock is a function of porosity (Equation 1).

Table 1 Depositional characteristics, diagenetic features and pore types of the Asmari Formation in the studied field. A homoclinal carbonate ramp platform, based on depositional evidence and facies association, is proposed for this formation in the studied area.

Lithology	Facies		Sedimentary Environment	Diagenetic Processes	Pore Types
Carbonates	Mud-dominated	Mudstone	intertidal-supratidal	dolomitization, anhydrite replacement	microporosity
		pelloidal Wackestone	lagoon	dolomitization, dissolution	microporosity
	Grain-dominated	pelloidal-skeletal Packstone	lagoon	dolomitization, anhydrite cementation, dissolution	dissolution vugs, microporosity
		pelloidal-skeletal Grainstone	shoal	cementation, dissolution	moldic, dissolution vugs
		ooid Grainstone	shoal	cementation, dissolution	intergranular, moldic
Sandstones		quartz Arenite, Litharenite, with minor quartz Wacke	coastal	_	intergranular

$1/V_{rock}=(1-\varphi)/V_{matrix}+\varphi/V_{fluid}$ (1)

In this equation, φ is the fractional porosity of the rock, V is compressional wave velocity of the formation (ft/sec), V_{fluid} is the velocity of interstitial fluids (ft/sec), and V_{matrix} is the velocity of rock matrix (ft/sec). From this equation, sonic porosity is calculated according to Equation 2.

$\varphi_s=(Dt-Dt_{matrix})/(Dt_{fluid}-Dt_{matrix})$ (2)

In this equation, Dt is the transition time of the wave through the formation based on the reading of the log, Dt_{matrix} and Dt_{fluid} are transition times of the wave through the rock matrix and the pores completely saturated with the fluid, respectively, and φ_s is sonic porosity. Therefore, for calculation of velocity deviation, it is needed to determine the difference between real velocity (V_{preal}) directly derived from sonic log (DT_{real}) and synthetic velocity (Vp_{syn}), derived from calculated sonic log (DT_{syn}) according to Equation 2. For calculation of DT_{syn}, computed φ_s from neutron or density logs were put in the equation. The transition time of wave through the rock (Dt_{matrix}) is based on the lithology of the studied formation (limestone, dolomite and sandstone) and the transition time of wave for the fluid (Dt_{fluid}) was put by default, 189.5 (μs/ft). Consequently, velocity deviation was determined by Equation 3.

Velocity Deviation= $Vp_{real}-Vp_{syn}=(304.8/DT_{real})*1000-(304.8/DT_{syn})*1000$ (3)

The extracted velocity deviation data as a continuous log were investigated for the reservoir interval along the studied wells, and changes in values of this parameter were connected with lithological characteristics, sedimentary textures, diagenetic features, and pore systems of the reservoir facies, which based on various reservoir rock types were differentiated.

Results and Discussion

Investigation of the core porosity and permeability data for sandstone and carbonate facies of the Asmari Formation in the study area shows that sandstone facies, in general, have higher reservoir quality than carbonate facies, as seen in Figure 2. Due to the variability of facies and the effect of diagenetic processes, the carbonates exhibit a wide range of porosity between low to high values. Still, their permeability is generally low, which indicates their pore system mainly consists of isolated pores, as seen in Figure 3A. In contrast, a high correlation coefficient value between core porosity and permeability data in sandstones is attributed to intergranular pore types in these facies (Fig. 3B). According to petrographic observations, the main pore types of carbonate facies are dissolution vugs and moldic, minor intergranular and intercrystalline ones showing various distribution in grain-dominated and mud-dominated facies of the reservoir (Figure 4).

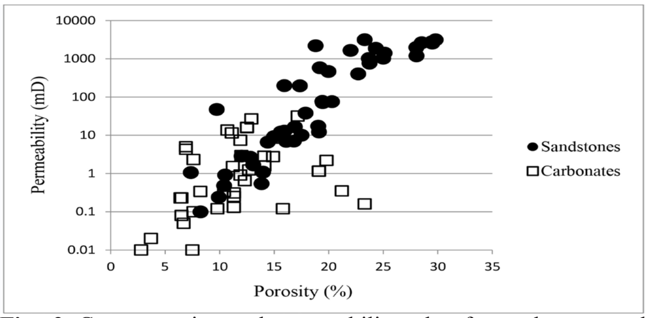

Fig. 2 Core porosity and permeability plot for carbonate and sandstone facies of the Asmari Formation in the studied field.

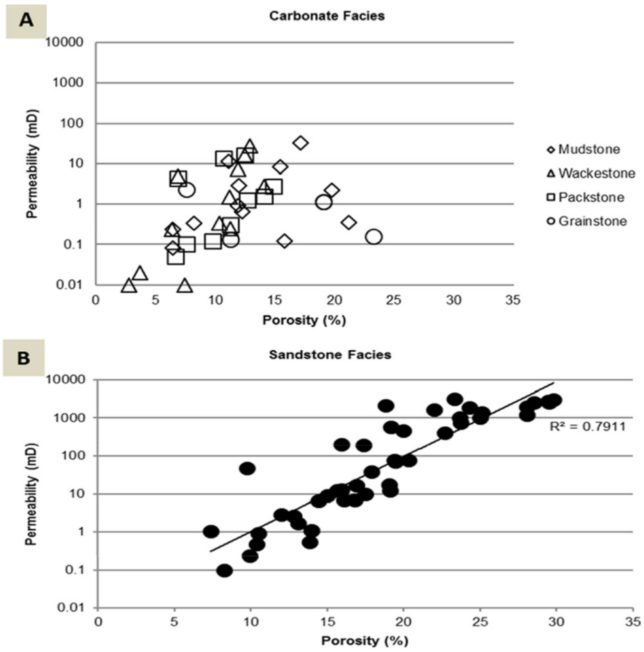

Fig. 3 Core porosity and permeability plot for different carbonate facies (A) and sandstones (B) of the Asmari Formation in the studied field. High correlation coefficient between porosity and permeability in sandstone facies is related to the presence of intergranular pore types in their pore system.

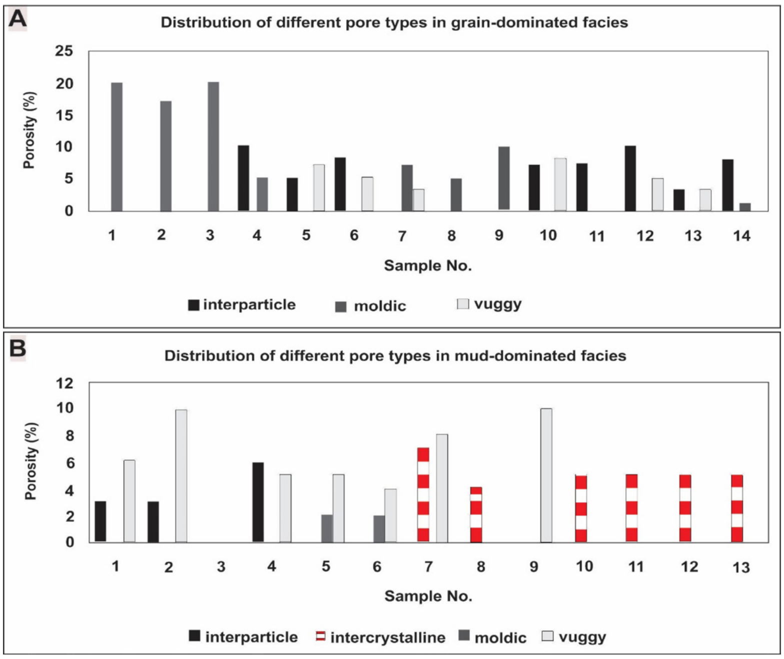

Fig. 4 Histograms showing the distribution of different pore types in grain- and mud-dominated carbonate facies based on petrographic analysis on a few samples of the Asmari reservoir in the studied field.

The results from the investigation of velocity deviation data were used to interpret the reservoir characteristics and pore types of the Asmari facies. Histograms of Figure 5 show variability of velocity deviation values for carbonate and sandstone facies. As it is evident from this figure, carbonate rocks exhibit a wide range of velocity deviation (Figs. 5A), which is attributed to their complex pore systems related to facies diversity and the effect of diagenesis. Variability in this parameter for mud-dominated and grain-dominated carbonate facies is shown in Figure 6. In comparison, sandstone facies, as mentioned above, show a narrow range of velocity deviation due to the uniform texture and intergranular porosity (Fig. 5B, Fig. 6).

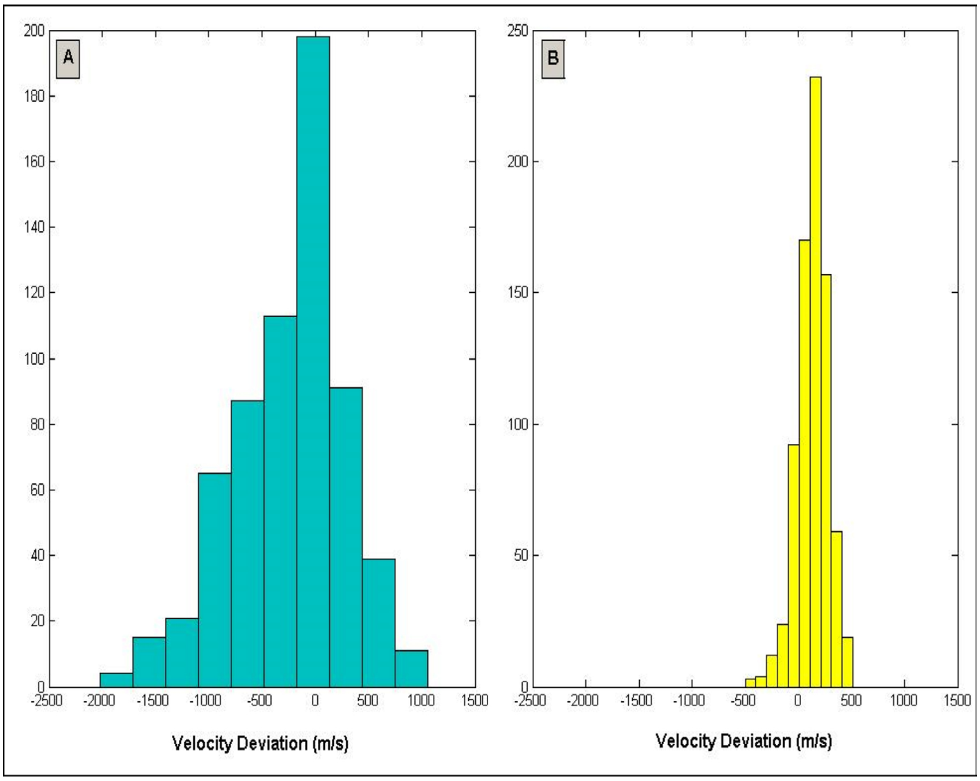

Fig. 5 Histograms showing variations in velocity deviation values in carbonate (A) and sandstone (B) facies of the Asmari Formation.

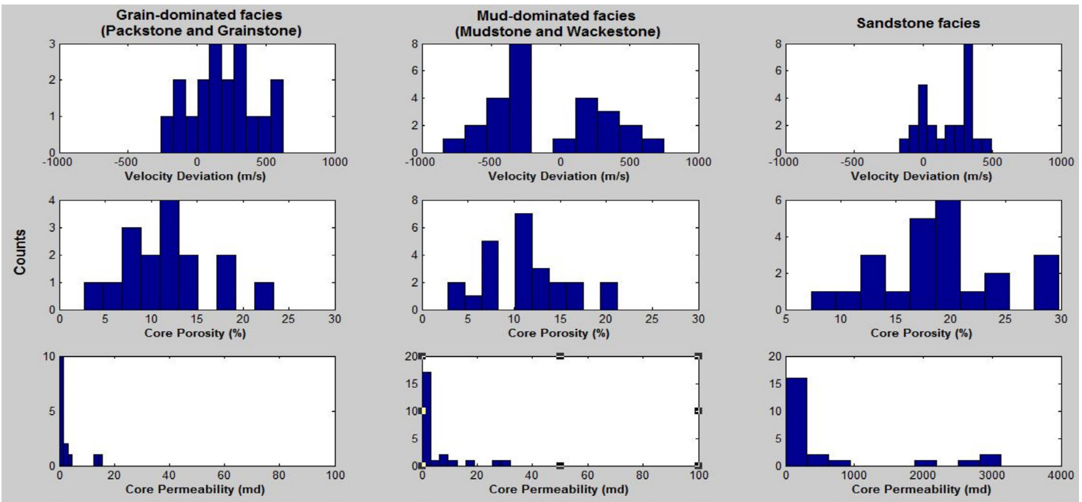

Fig. 6 The extracted velocity deviation values associated with core porosity and permeability data for carbonate (mud-dominated and grain-dominated) and sandstone facies of the Asmari Formation in the studied field.

Therefore, variations in velocity deviation were more analyzed for the reservoir carbonates using the clustering method. For this purpose, statistical operations were run on velocity deviation data for these facies in MATLAB software. In this respect, using a specified distance function (Euclidean function) that examines the statistical distances between the input data and a linkage function for making statistical connection between distance data, clustering tree (dendrogram) for differentiation of different data sets (clusters) was extracted. The extracted dendrogram is shown in Figure 7. According to this figure, three main clusters of data based on the selected cut-off value can be differentiated. Based on the study results of petrographic observations, these clusters show a good consistency with internal reservoir heterogeneity derived from depositional and diagenetic characteristics of the Asmari carbonates and their reservoir properties. The identified clusters show three different rock types related to depositional /diagenetic characteristics and pore system properties of carbonate facies.

In contrast, sandstone facies that show a narrower range of velocity deviation and a relatively homogenous texture were classified in one group. In Figure 8, the range of velocity deviation values for various rock types identified in the reservoir is shown. In addition, variations in this parameter with porosity values for each rock type are shown in Figure 9. These rock types in association with sandstone facies are described as follows:

Rocky Type 1 (RT-1): Carbonate facies in this rock type under the influence of mud-dominated texture (mudstone and wackestone) and also anhydrite cementation are characterized by negative values of velocity deviation (highly negative skewness on the histogram) and very low porosity (Figs. 8 and 9A). This rock type includes carbonates of low reservoir quality or tight carbonates, and it covers cemented and low permeable zones of the reservoir.

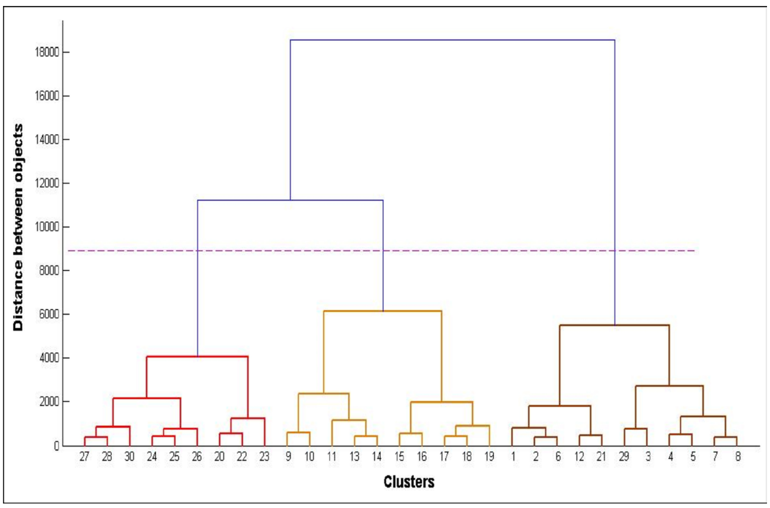

Fig. 7 The extracted dendrogram for clustering velocity deviation data of carbonate facies in the Asmari Formation. The horizontal dashed line on the diagram shows the cut-off value for differentiation of clusters.

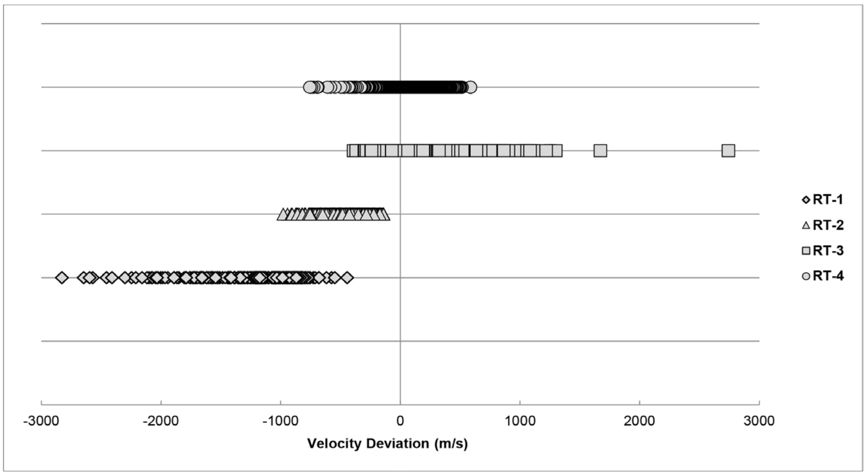

Fig. 8 Range of velocity deviation values for the identified rock types (RT-1 to RT-4) in the studied reservoir.

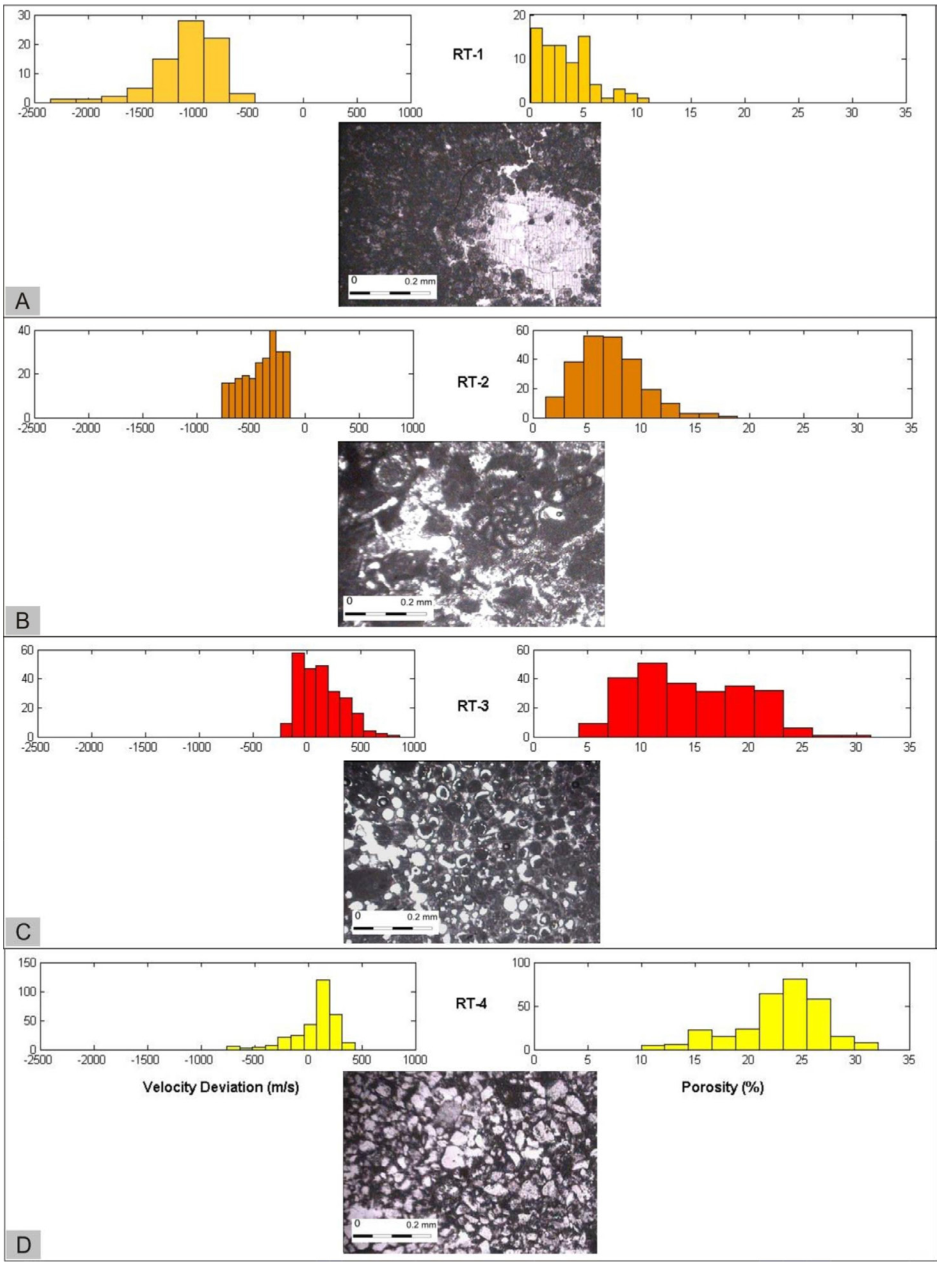

Fig. 9 Variations in velocity deviation and porosity values for different rocks types of the Asmari Formation (A=RT-1, B=RT-2, C=RT-3, and D=RT-4).

Rock Type 2 (RT-2): Carbonate facies in this rock type have a mud-dominated texture (Wackestone), and their pore system consists of micropores and isolated vugs within the matrix. In addition, a part of their pore system has been affected by cementation. Therefore, velocity deviation in this rock type tends towards negative values (negative skewness on the histogram) but is lower than that observed in RT-1 (Figs. 8 and 9B). It is characterized by carbonates of low to medium porosity values.

Rocky Type 3 (RT-3): This rock type consists of carbonate facies with high porosity related to moldic pores and isolated dissolution vugs within grainstone and grain-dominated packstone facies. The velocity deviation in these facies tends towards high positive values (positive skewness on the histogram) (Figs. 8 and 9C). The values close to zero of this parameter are attributed to a minor percent of primary intergranular pore types present in some facies of this rock type.

Rock Type 4 (RT-4): This rock type consists of sandstone facies with high porosity. These facies are mostly loose with pore systems consisting of connected intergranular pore types. The velocity deviation values show a narrow range (symmetrical or near zero skewness on the histogram) (Figs. 8 and 9D).

A study of the identified carbonate rock types regarding their pore system properties indicates the role of diagenetic processes (cementation and dissolution) as the main controlling factors of reservoir heterogeneity of the Asmari carbonates. This can be approved by cemented facies of low reservoir quality (RT-1), and the presence of moldic pores and isolated vugs (RT-2, RT-3), especially in grain-dominated carbonate facies. Therefore, the identified carbonate rock types are an indication of diagenetic facies with certain pore types and reservoir quality. Figure 10 demonstrates the identified rock types or diagenetic facies on the velocity deviation-porosity plot. According to this figure, porosity increases from RT-1 towards RT3 and RT-4. Rock typing based on the velocity deviation log used in this study and adapting to the sedimentary and diagenetic characteristics of reservoir rocks also reveals their reservoir characteristics and pore type. These results can be compared with other rock typing methods such as electrofacies and flow units.

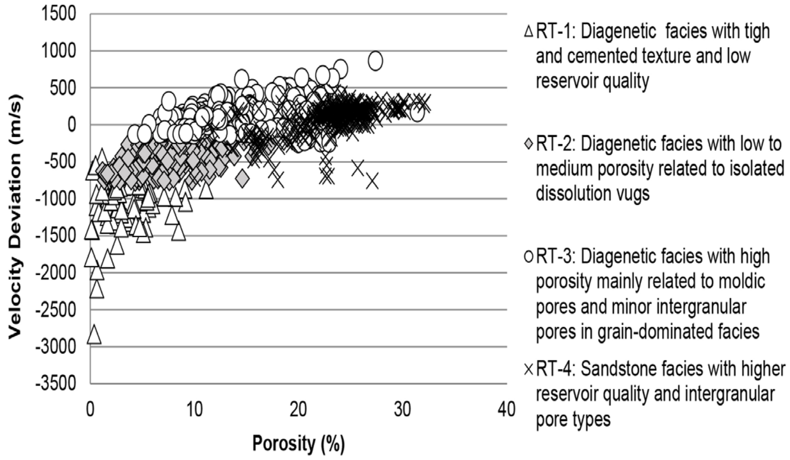

Fig. 10 Comparison of different rock types of the Asmari Formation on velocity deviation-porosity plot.

In Figure 11, velocity deviation is shown as a continuous log (VDL), related to the identified rock types and reservoir zones (Z1 to Z6) within the Asmari Formation in the studied wells. The velocity deviation log shows wide variations in the upper zones (Z1 and Z2), where carbonate rocks are dominant with different facies and pore types (RT1, RT2 and RT3). In contrast, sandstone facies with uniform and narrower VDL values (RT4) are more dominant in the middle parts of the formation (Z3 and Z5).

These facies with high values of porosity and permeability include the most promising reservoir units in the field. Shaly and argillaceous facies, mainly in lower parts of the formation (Z6), have been ignored in VDL calculation for the reservoir interval (VDL=0 by default).

From a sequence stratigraphic point of view, the development of the Asmari Formation with a mixed clastic-carbonate lithology in the studied area has been started with the entrance of clastic facies (shale and sand) sourced from the Arabian Plate through the interaction between tectonic and relative sea-level changes [40]. Therefore, the clastic facies in the lower and middle parts of the formation (mostly Z3, Z5 and Z6) are related to falling stages of sea level. Clastic input from the hinterland is continued until the condition for carbonate deposition is provided by the dominance of marine conditions during sea-level rise. Interlayers of shale and sandstone units in the middle and upper parts of the formation (Z2, Z3, and Z4) indicate a gradual change in environmental condition from clastic (Z5 and Z6) to shallow marine carbonate (in Z1) environment. Finally, the deposition of evaporites of the Gachsaran Formation as a cap rock indicates the falling stage of sea level and the end of the sedimentary cycle. Due to the complex pore systems reflected by wide variations in velocity deviation within the reservoir interval, carbonate facies have the main control on vertical reservoir heterogeneity. In contrast, sandstone facies mainly control the horizontal reservoir heterogeneity through the variation in thickness and lateral continuity of reservoir zones in the field.

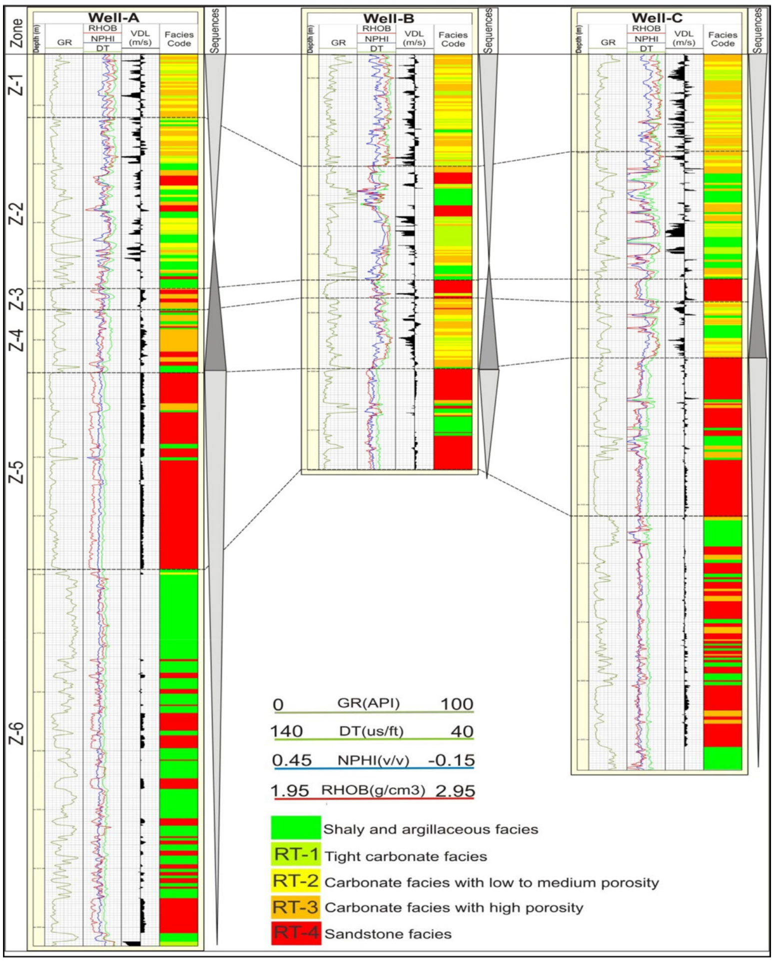

Fig. 11 Velocity deviation log (VDL) in relation to the identified rock types and reservoir zones of the Asmari Formation along the studied wells.

Conclusions

Investigation of carbonate and sandstone facies of the Asmari Formation based on the velocity deviation log to unravel the reservoir heterogeneity in the studied field led to the identification of four different rock types (RT-1 to RT-4). Carbonate facies show wide variations (negative to positive values) in the velocity deviation log that is consistent with diversity in depositional texture and especially the effect of diagenesis on their pore system properties. The results show that the variations in this log can be precisely correlated with pore systems properties of the reservoir rocks. Because diagenesis has the main control on reservoir characteristics and pore system properties of carbonate facies, the identified carbonate rock types (RT1, RT2 and RT3) indicate diagenetic facies with certain pore types and reservoir quality. In contrast, sandstone facies of RT4, under the influence of depositional texture and connected pore types, are characterized by a narrow range (near zero) of this parameter and high reservoir quality. Carbonate facies of the Asmari Formation with complex pore systems mainly control vertical reservoir heterogeneity, while sandstone facies play the main role in horizontal reservoir heterogeneity through the variations in thickness and lateral continuity of reservoir zones in the studied field.

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References

1. Aliakbardoust E, Rahimpour-Bonab H (2013) Effects of pore geometry and rock properties on water saturation of a carbonate reservoir, Journal of Petroleum Science and Engineering, 112: 296-309.
2. Hollis C, Vahrenkamp V, Tull S, Mookerjee A, Taberner C, Huang Y (2010) Pore system characterisation in heterogeneous carbonates: An alternative approach to widely-used rock-typing methodologies, Marine and Petroleum Geology, 27: 772-793.
3. Ahmed T (2010) Reservoir Engineering Handbook, Gulf Professional Publishing (4th ed.), 1472.
4. Fitch P, Davies S, Lovell M, Tim Pritchard T, Sirju C (2010) Heterogeneity in carbonate petrophysical properties: Application to fluid flow units and sampling strategies, SPWLA 51st Annual Logging Symposium, Perth, Australia, SPWLA-2010-92910.
5. Flugel E, Munecke A (2010) Micofacies of carbonate rocks: analysis, interpretation and application, Springer (2th ed.), Berlin, 1007.

6. James N P, Jones B (2016) Origin of carbonate of carbonate sedimentary rocks, Wiley, Chichester, 446.
7. Moore C H, Wade W J (2013) Carbonate reservoirs: porosity and diagenesis in a sequence stratigraphic framework, Elsevier (2th ed.), Kidlington, 392.
8. Henares S, Caracciolo L, Cultrone G, Fernandez J, Viseras C (2014) The role of diagenesis and depositional facies on pore system evolution in a Triassic outcrop analogue (SE Spain), Marine and Petroleum Geology, 51: 136-151.
9. Liu H, Tian Z, Liu B, Guo R, Yang D, Deng Y, Yu Y, Shi K (2018) Pore types, origins and control on reservoir heterogeneity of carbonate rocks in Middle Cretaceous Mishrif Formation of the West Qurna oilfield, Iraq, Journal of Petroleum Science and Engineering, 171: 1338-1349.
10. Ehrenberg S N (2006) Porosity destruction in carbonate platforms, Journal of Petroleum Geology, 29: 41-52.
11. Rezaee M R, Jafari A, Kazemzadeh E (2006) Relationships between permeability, porosity and pore throat size in carbonate rocks using regression analysis and neural networks, Journal of Geophysics and Engineering, 3(4): 370-376.
12. Chehrazi A, Rezaee R, Rahimpour-Bonab H (2011) Pore-facies as a tool for incorporation of small-scale dynamic information in integrated reservoir studies, Journal of Geophysics and Engineering, 8: 202-224.
13. Rahimpour-Bonab H, Aliakbardoust E¬ (2014) Pore facies analysis: incorporation of rock properties into pore geometry based classes in a Permo-Triassic carbonate reservoir in the Persian Gulf, Journal of Geophysics and Engineering, 11, 3: 035008.
14. Sfidari E, Kadkhodaie A, Ahmadi B, Ahmadi B, Faraji M A, (2018) Prediction of pore facies using GMDH-type neural networks: a case study from the South Pars gas field, Persian Gulf basin, Geopersia, 8, 1: 43-60.
15. Lubis L, Harith ZZT (2014) Integration of rock digital images to improve carbonate rock physics model of offshore sarawak, Journal of Applied Sciences, 14: 3354-3358.
16. Wyllie MR, Gregory AR, Gardner G H F (1956) Elastic wave velocities in heterogeneous and porous media, Geophysics, 21(1): 41-70.
17. Wyllie MR, Gregory AR, Gardner G H F (1958) An experimental investigation of factors affecting elastic wave velocities in porous media, Geophysics, 23, 3: 459-493.
18. Wyllie M R, Gregory A R, Gardner G H F (1962) Studies of elastic wave attenuation in porous media, Geophysics, 27, 5: 569-589.
19. Gardner G H F, Gardner L W, Gregory A R (1974) Formation velocity and density: the diagnostic basics for stratigraphic traps, Geophysics, 39: 770-780.
20. Raymer L L, Hunt E R, Gardner JS (1980) An improved sonic transit time to porosity transform, In: 21st Annual Society of Professional Well Log Analysts Logging Symposium, Transactions, 8-11 July, Lafayette.
21. Bashah S, Pierson B (2012) The Impact of pore geometry and microporosity on velocity porosity relationship in carbonates of central luconia, Sarawak, Adapted from extended abstract prepared in conjunction with oral presentation at AAPG International Conference and Exhibition, Singapore.
22. Berg B V, Grammer M, Eberli G, Weger R (2013) Combining pore architecture and sonic velocity response to predict reservoir quality: an example from a mid-continent mississippian carbonate, Adapted from an oral presentation given at AAPG Mid-Continent Section Meeting, Wichita, Kansas.
23. Anselmetti F S, Eberli G P (1999) The velocity-deviation log: A tool to predict pore type and permeability trends in carbonate drill holes from sonic and porosity or density logs, AAPG Bulletin, 83, 3: 450-466.
24. Shirmohamadi M, Kadkhodaie A, Rahimpour-Bonab H, Faraji MA (2017) Seismic velocity deviation log: An effective method for evaluating spatial distribution of reservoir pore types, Journal of Applied Geophysics, 139: 223-238.
25. Nazemi M, Tavakoli V, Rahimpour-Bonab H, Hosseini M, Sharifi-Yazdi M (2018) The effect of carbonate reservoir heterogeneity on archie's exponents (a and m), an example from kangan and dalan gas formations in the Central Persian Gulf, Journal of Natural Gas Science and Engineering, 59: 297-308.
26. Kakhodaie R, Jodeiri-Agaii R (2018) Reservoir zonation of the Cenomanian-early Turonian Mishrif Formation using velocity deviation log in Sirri Esfand oilfield of the Persian Gulf, Applied Sedimentology, 6, 12: 103-111.
27. Yarmohammadi S, Kadkhodaie A, Hosseinzadeh, S (2020) An integrated approach for heterogeneity analysis of carbonate reservoirs by using image log based porosity distributions, NMR T2 curves, velocity deviation log and petrographic studies: A case study from the South Pars gas field, Persian Gulf Basin, Journal of Petroleum Science and Engineering, 192, 1: 107283
28. Kadkhodaie-Ilkhchi R, Kadkhodaie-Ilkhchi A, Rezaee R (2021) Study of pore system properties of tight gas sandstones based on analysis of the seismically derived velocity deviation log: A case study from the Perth Basin of western Australia, Journal of Petroleum Science and Engineering, 196: 108077.
29. Honarmand J, Amini A (2017) Diagenetic processes and reservoir properties in the ooid grainstones of the Asmari Formation, Cheshmeh Khush Oil Field, SW Iran, Journal of Petroleum Science and Engineering 81: 70-79
30. Aghli G, Moussavi-Harami R, Tokhmechi, B (2020) Integration of sonic and resistivity conventional logs for identification of fracture parameters in the carbonate reservoirs (A case study, Carbonate Asmari Formation, Zagros Basin, SW Iran), Journal of Petroleum Science and Engineering, 186: 106728.
31. Gharechelou S, Amini A, Bohloli B, Swennen R (2020) Relationship between the sedimentary microfacies and geomechanical behavior of the Asmari Formation carbonates, southwestern Iran., Marine and Petroleum Geology, 116: 104306.
32. Noorian Y, Moussavi-Harami R, Reijmer JJG, Mahboubi A, Kadkhodaie A, Omidpour A (2021) Paleo-facies distribution and sequence stratigraphic architecture

of the Oligo-Miocene Asmari carbonate platform (southeast Dezful Embayment, Zagros Basin, SW Iran), Marine and Petroleum Geology, 128: 105016.
33. Omidpour A, Mahboubi A, Moussavi-Harami R, Rahimpour-Bonab H (2022) Effects of dolomitization on porosity – Permeability distribution in depositional sequences and its effects on reservoir quality, a case from Asmari Formation, SW Iran, Journal of Petroleum Science and Engineering, 208 (Part A): 109348.
34. Honarmand J (2013) Sedimentological and diagenetic controls on reservoir properties of the Asmari formation, Cheshmeh–Khosh field, northern part of Dezful Embayment, SW Iran, Ph.D. dissertation University of Tehran, Tehran.
35. Gharechelou S, Daraei M, Amini A (2016) Pore types distribution and their reservoir properties in the sequence stratigraphic framework: a case study from the Oligo-Miocene Asmari Formation, SW Iran, Arabian Journal of Geosciences, 9:194.
36. Motiei H (1995) Petroleum Geology of Zagros, Geological Survey of Iran Publication, 589.
37. Schlumberger (1974) Log interpretation-applications, New York, Schlumberger Limited, 2, 116.
38. Schlumberger (1972) Log interpretation-principles, New York, Schlumberger Limited, 1, 113.
39. Asquith G B (1985) Handbook of log evaluation techniques for carbonate reservoirs, AAPG Methods in Exploration Series 5, 47.
40. Daraei M, Bayet-Gol A, Ansari M (2017) An integrated reservoir zonation in sequence stratigraphic framework: A case from the Dezful Embayment, Zagros, Iran. Journal of Petroleum Science and Engineering, 154: 389-404.