Kurdistan Journal of Applied Research (KJAR)
Print-ISSN: 2411-7684 | Electronic-ISSN: 2411-7706

Website: Kjar.spu.edu.iq | Email: kjar@spu.edu.iq

Reservoir Productivity Analysis of Intercalated limestone and Anhydrite Beds in Zagros Folded Belt, Kurdistan Region of Iraq

Fraidoon Rashid
Department of Engineering
Kurdistan Institution for Strategic Study and Scientific Research
Sulaimani, Iraq
fraidoon.rashid@kissr.edu.krd

Article Info

Volume 5 – Issue 1 – June 2020

DOI:
10.24017/science.2020.1.1

Article history:

Received: 09/02/2020
Accepted: 26/02/2020

ABSTRACT

The Early Jurassic rock of Alan Formation in Barda Rash field have been examined using petrophysical wireline log analysis, drilling stem test, mud logging reports, drilling cutting and core samples for evaluation of reservoir potentiality and fluid production throughout heterogeneous rocks intervals in three exploration and appraisal wells. The Alan Formation consists of intercalation of light, chalky and argillaceous limestone beds with shale layers in the upper part and dominantly anhydrite layers from the middle to the lower parts of the formation. Qualitatively, weak oil shows of light brown to dark brown and blackish heavy oil have been observed while drilling. Furthermore, light brown trace oil has been recorded in the fracture surfaces of the core samples. The wireline log analysis provided an overestimated result for the hydrocarbon bearing interval identification and fluid movability index as the anhydrite layers confused the fluid distribution detection in the drilled interval. However, the combined results achieved from the mud logging reports and drilling stem tests were operated with in the drilled intervals shown a limited productivity levels from the limestone beds of the Early Jurassic Alan Formation. The oil production from the studied interval does not exceed 10% and the entire production rates were composed of formation water with a trace amount of gases. As a result, the Early Jurassic Alan Formation can be considered as a tight carbonate reservoir rocks in the Barda Rash field.

Keywords:

Alan Formation,
Carbonate,
Well test,
Hydrocarbon,
Petrophysics,
Zagros Basin

1. INTRODUCTION

The newly discovered fields in the Kurdistan region of Iraq contain multiple petroleum systems and isotropic reservoir rocks from Triassic to Tertiary rocks type with extensive fracture distributions and variable hydrocarbon qualities throughout NW-SE elongated surface and sub-surface structures [1, 2, 3, 4, 5, 6, 7]. The dominant proved hydrocarbons were expelled from organic rich shale and carbonate rocks of Triassic and Jurassic formations and entrapped in the heterogeneous and highly fractured carbonate reservoir rocks of the Cretaceous and Tertiary rocks in Zagros folded belt [8, 9,10].

The investigated source rocks have variable potentiality and distinctive geochemical properties [11, 12, 13]. Besides of the source rock potentiality behaviors of the Triassic-Jurassic rocks throughout the Kurdistan region fields, these successions are considered as a productive reservoir rocks including the Upper Triassic Kurra Chine Formation in Shaikan Field [14] Jurassic Barsarin, Sargelu, Alan, Mus, Adaiyah, Butmah Formations in Atrush field [15] and Jurassic Sargelu, Mus and Butmah formations in the Shaikan Field [16].

In this work, Jurassic Alan Formation in Barda Rash field in the Zagros Folded Belt is being selected, that previously identified as a source rock in Qarachuq and Jabal Qand [17] and Miran West field [18]. The objectives of this research are to use wireline log information, well tests and rock description to understand variations in the stratigraphy and fluid movability of the Alan Formation across the field, to assess the lithology and fluid distribution of the reservoirs, and to ascertain how the petrophysical properties of the rocks include porosity and shale volume vary, taking particular role of heterogeneity and anisotropy. These improve the understanding of the lithology variation influences on the reservoir quality including porosity, permeability, and productivity with document potential reservoir intervals in term of available fluid movability.

2. STUDY AREA

Barda Rash Block is located in the Kurdistan region of northern Iraq, close to the northern boundary of the NW-SE trending Kirkuk Embayment region of the Zagros Fold and Thrust Belt. This region contains several NW-SE trending subsurface structures included Kirkuk, Jambur, Khabaz, Bai Hassan, Chamchamal and Taq Taq anticlines. The Barda Rash anticline lies in the folded foothills to the southwest of the Mountain Front Fault, which separates the High Zagros Mountains from the Kirkuk Embayment [19, 8, 20, 21].

The structure is elongated anticlinal developed on the direction NW-SE with approximately longitudinal axis of 20 km and cross axis of 6 km, Figure (1). The anticline is flanked to the north and south by two major tectonic accidents jumps by about 300-500m towards the north-western flank and about 200-400m towards south-eastern flank, developed approximately parallel to the axis and gave the appearance like a horst of the structure [22]. This anticline is suited geographically about 25 km north-east of Mosul city from the northwest side. The Barda Rash structure is bound to the northwest by the AL Khazir River and by Sarta and Ain Sifni structures; to the southeast, by Ain-Al-Safra structure; to the south, by the Bashiqa and Maqloub structures to the northwest. The Miocene-Pliocene Upper Fars-Lower Fars and Bakhtiari formations are cropping out at the surface on and near Barda Rash anticline.

Three wells have been drilled on this structure during exploration stage. The exploration well number 1 (BR-1) was drilled close to the crest of the Barda Rash fold, and has mainly targeted to explore Cretaceous, Jurassic and Triassic successions to investigate and estimate fluid content in these intervals [22]. The exploration Well number 2 (BR-2) is the second on the anticline and was drilled on the north-west of the well BR-1. This well was targeted to explore and prove Jurassic formations and identify the fluid content in these formations. The third exploration well (BR-3) was drilled on south-east of the well BR-1 with a distance about 10 km. This well was drilled for proving the Jurassic formations extension and estimation of the fluid content [23, 24].

3. METHODS AND MATERIALS

The gathered data for this work consists of a wireline log data sets from open and non-cased drilled wells from the Jurassic Alan Formation intervals throughout three exploration wells including BR-1, BR-2 and BR-3 in Barda Rash block. The wireline logs contain the three types of porosity derived logs (Sonic, Density, and Neutron), nuclear radiation gamma ray log, electrical resistivity logs and drawn lithologies strip log. In addition, drilling stem test (DST), mud Log reports, core samples and drilled cutting samples have been intercalated with the physical parameters of the logs to improve the reservoir parameters measurements.

The achieved data for this study is summarized the table (1).

The LAS format of the wireline logs data have been applied to determine the lithology characterisation, shale volume calculations, porosity counting and fluid content estimation in the Alan Formation using Interactive Petrophysics (IP). The log analysis results have been integrated with lithologic description of cutting and core samples, oil show investigation and well test results of the selected wells

3.1. Lithology

Wireline log interpretation is one of the common and effective methods in petroleum industry use to identify hydrocarbon bearing interval, reservoir thickness, fluid type distribution, and to predict a reservoir potentiality by identification of physical properties of the subsurface rocks including the magnitude of porosity, pore geometry and pore filling types [25, 26]. Lithological investigation is the dominant result can be achieved from the conventional wireline log analysis. In this analysis limestone, dolomite, anhydrite and clay have been assumed to be present, and the log tool responses (neutron (NPHI), density (RHOB), gamma ray (GR), sonic (DT) have been used to describe the mineral components of the studied intervals.

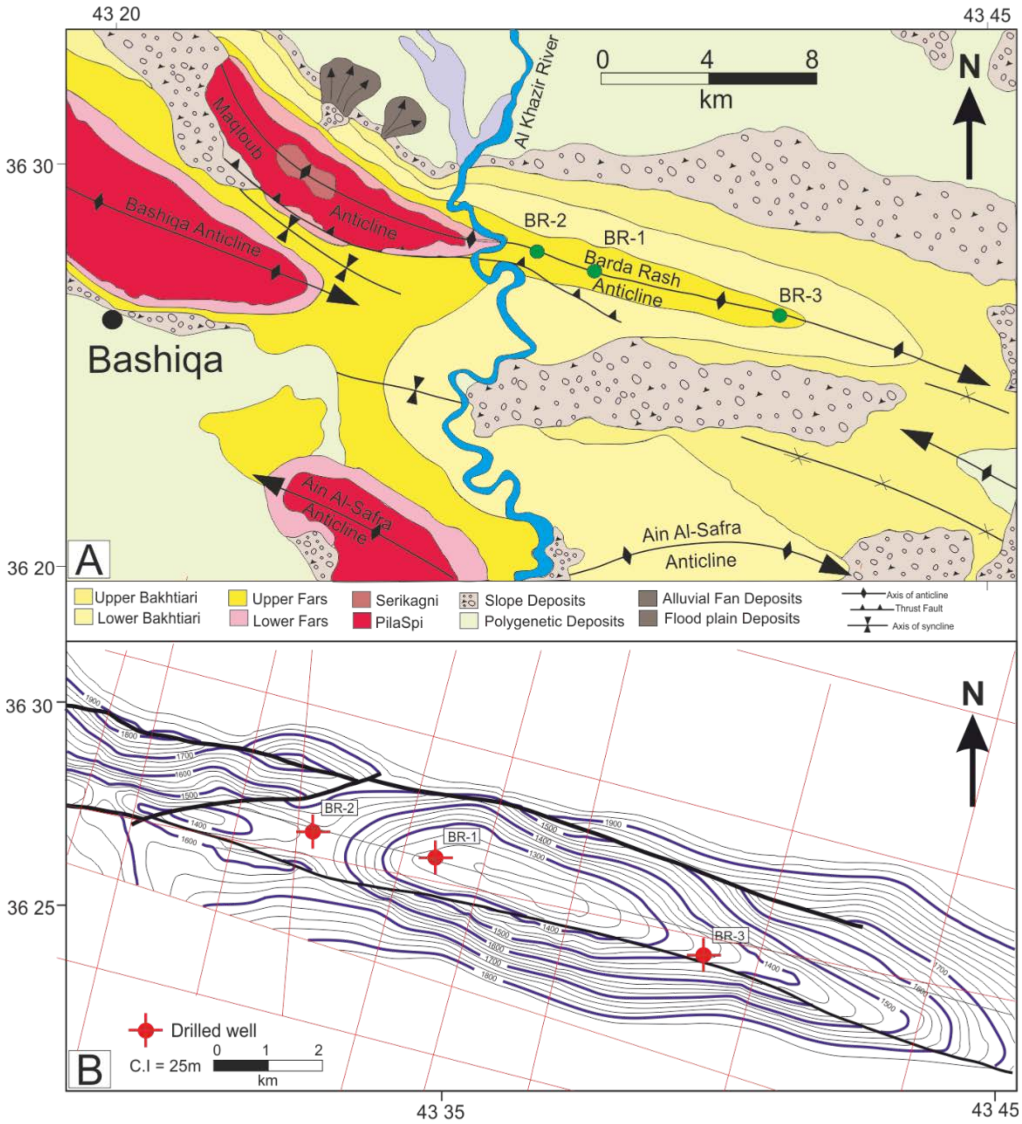

Figure 1: Maps show the position of the Barda Rash structure and selected wells. (a) Geologic map of the study area and nearby structures shows the Barda Rash anticline and drilled well positions modified after [27, 28]. (b) Contour map was drawn on the top of Jurassic Formations throughout the Barda Rash structure [22, 23, 24].

The porosity logs have a difference respond to lithological variations and fluid filled pore types, as a result based on the combination of two or all three types of the logs, porosity types and lithology types can be identified clearly for a logged interval [25, 26 and 30]. Furthermore, log cross plots give potential results for mineralogical and lithological components examination. The wireline logs cross plots work based on the slope and intersect of two types of porosity logs response, dependent on matrix lithology and pore fluid [29, 31, 25, and 26]. Density-Neutron and Neutron-Sonic cross plots are the two essential plots that dominantly used in mineralogical analysis from the petrophysical wireline logs. The outcomes of the lithological investigation from the wireline log data have been integrated with the lithologic description of drilling cutting samples and available core samples of the same logged interval in the selected wells.

Table 1: Summary of the gathered data from the selected wells in the Barda Rash

Data	BR-1	BR-2	BR-2
Wireline Log	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)
Cutting sample	36	48	44
Core sample	-	40 meters	-
Well Test	DST	DST	DST
Mud Log	Mud losses report	Mud losses report	Mud losses report

3.2. *Shale Content*

Gamma ray log was applied for estimating shale volume content in the studied intervals. The volume of shale (V_{sh}) depends on the magnitude of gamma ray index for each interval throughout the studied field. The gamma ray index (IGR) was calculated using equation (1) from the shale base line (gamma reading = 100 API, maximum gamma ray reading), clean sand line (gamma reading= 5.0 API, minimum gamma ray reading) were obtained from the logged well and the gamma ray log reading from the selected interval [32].

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

IGR : Gamma ray index.
GR_{log} : Gamma ray reading from log, API.
GR_{min}: Minimum gamma ray reading (clean carbonate), API.
GR_{max} : Maximum gamma ray reading (shale), API.

The non linear relation models (Larionov, 1969) who predicted the volume of shale based on geological age using older (pre-Tertiary) consolidated rocks was applied for the shale volume calculation, equation (2).

$$V_{sh} = 0.33(2^{2I_{GR}} - 1) \quad (2)$$

V_{sh} : Shale volume.

3.3. *Porosity*

The porosity logs have been used to determine the magnitude of porosity in the studied intervals. The apparent density was collected from the reading of the density logs in combination with value of the standard matrix density and the fluids occupying the pores was converted to the density log derived porosity with applying equation (3). In addition, the hydrogen concentration was recorded from the neutron log can be immediately transferred to neutron porosity [29, 33]. The Total log porosity was obtained from the mean value of the density derived porosity and neutron porosity, equation (4) and eventually corrected for the shale content for all intervals , equation (5).

$$\phi_{\rho} = \frac{(\rho_{ma} - \rho_{bulk})}{(\rho_{ma} - \rho_{fl})} \quad (3)$$

ϕ_ρ: Density porosity, fraction.
ρ_{ma}: Matrix density, g/cm3.
ρ_{bulk}: Log reading density, g/cm3.
ρ_{fl}: Fluid density, g/cm3.

$$\phi_T = \frac{\phi_\rho + \phi_N}{2} \quad (4)$$

ϕ_T: Total porosity, fraction.
ϕ_N : Neutron derived porosity, fraction.

$$\phi_E = \phi_T - (1 - V_{sh}) \quad (5)$$

ϕ_E: Effective porosity, fraction.

4. RESULTS AND DISCUSSION

The Jurassic Alan Formation was first described from subsurface section in well Alan-1 in the northwestern part of Iraq as 87 meters of intercalation of anhydrite and limestone beds [34, 35, 20]. In the Barda Rash field this formation composed of alternation of shales, limestones and anhydrite beds at the top and these components change to intercalation of anhydrite and limestone beds from the middle to the bottom of the formation interval, Figure (2) and Figure 3 (A and B). The maximum thickness of the Alan Formation in Barda Rash field at the current stage was recorded in well BR-2 as 245m and this thickness become 185m in well BR-1 and 220m in well BR-3.

Shale layers are characterised by dark brown to blackish colour, soft, compacted and occasionally fissile of rocks that dominantly have calcareous composition. The limestone beds are consisting of mudstone to wackestone microfacies with argillaceous and chalky components.

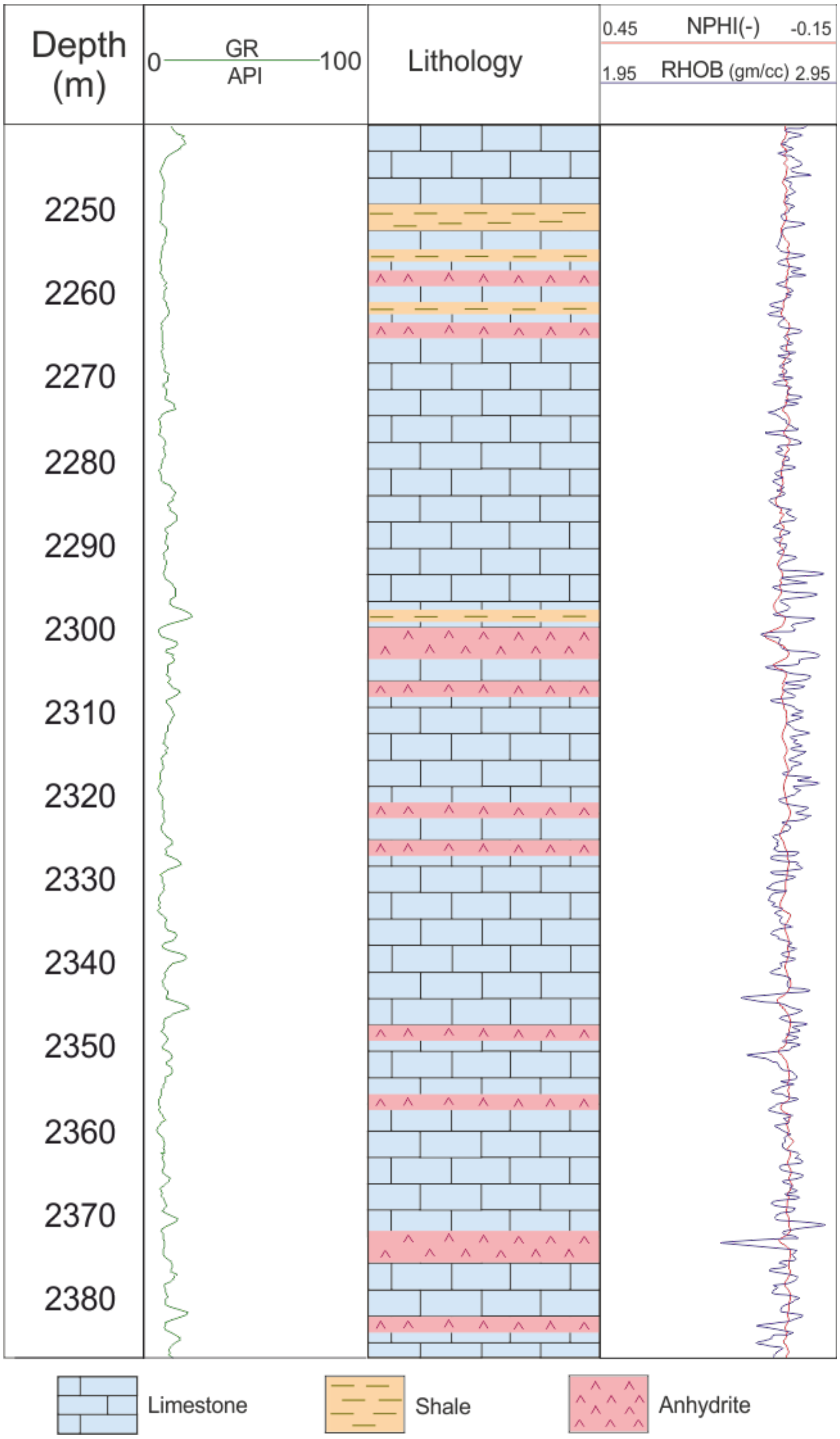

Figure 2: Typical Stratigraphic column of the Jurassic Alan Formation in well BR-1. The lithological components were drawn based on rock description of core samples, cutting samples and wireline log analysis.

These beds have light brown to dark brown colour, moderately hard, and fine crystalline texture with poor observed pores and weak oil show observation in well BR-1 and BR-3 but light brown to dark brown and blackish heavy oil as oil shows have been observed in well BR-2 as patchy to uniform oil stain distribution on fissures that gave a strong oil order to the drilled intervals, Figure 3 (C and D). Anhydrite beds were commonly recorded in the middle and lower part of the formation can be identified as white colour to occasionally pearlescent, soft and amorphous microstructure rocks intercalated with limestone beds. In pores of the limestone beds, brown to dark brown oil stain, spotty oil stain; moderately to good oil shows, moderately trace of oil have been recorded.

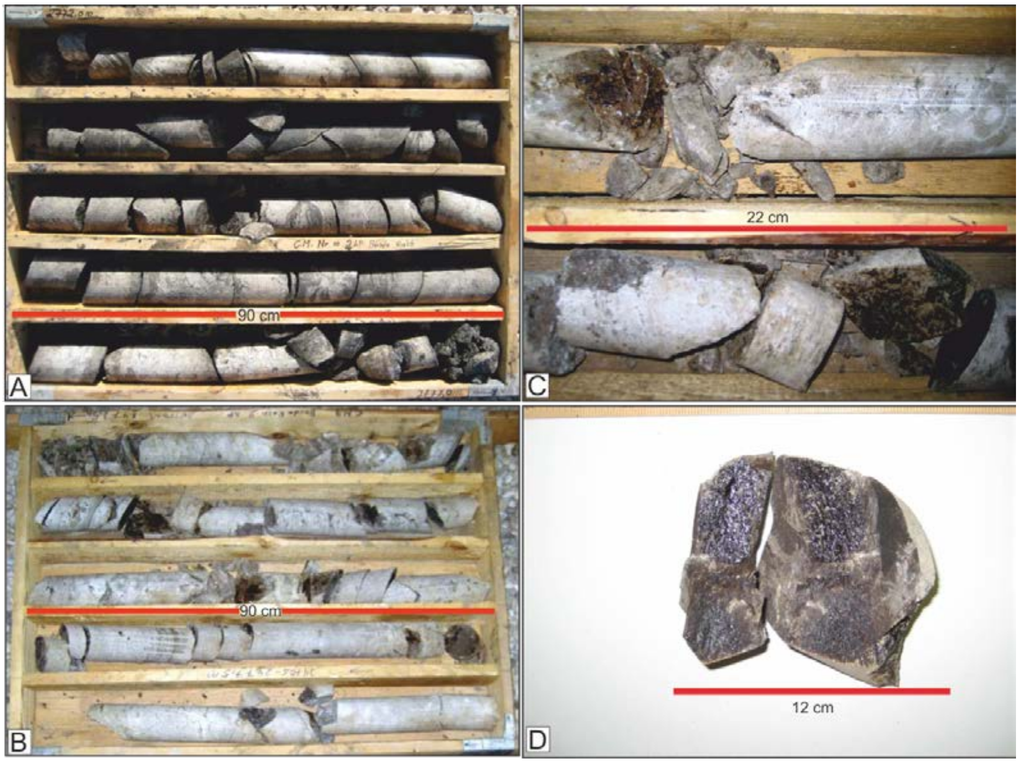

Figure 3: Core samples drilled from the early Jurassic Alan Formation in well BR-2 in the Barda Rash field. (a) Light grey, argillaceous and compacted limestone, 2772m-2777m. (a) Light brown, soft and chalky limestone, 2470.5m-2475.5m. (c) Light brown oil observed on the fractured surfaces of limestone beds, 2475.5m-2477.5m. (d) Dark brown to blackish heavy oil recorded on the surfaces of fractures of dark grey limestone beds.

The estimated shale contents were achieved from the gamma ray log reading by applying the equation number (1) and (2) respectively for the drilled intervals throughout the study wells. The magnitude of calculated shale volume in the Alan Formation changed apparently between the wells. The shale volume in both wells of BR-1 and BR-3 are similar and the amounts of shale in these two wells are lower than in BR-2, Figure 4 (A, B, and C). Overall, the percentages of the maximum shale contents in the Alan Formation have reached to 20% in the well BR-1 and BR-3, while this amount is enhanced to 30 % in well BR-3.

The calculated effective porosity was obtained from the mean values of the density log derived porosity and the neutron derived porosity of the Alan Formation and the impactions of shale contents have been corrected. As a result, the porosity value is considered as an effective porosity. The deflections of the total porosities have not had uniform and regular distribution throughout the drilled intervals. The magnitude of the porosity has nearly similar ranges in the Alan Formation throughout the studied field. The porosity values started from 0.0 from anhydrite beds to 0.12 for limestone beds with an average of 0.003 in well BR-1, Figure 4 (D, E, and F). The magnitude of porosity in well BR-2 starts from 0.0 to 0.24 with an average of 0.053 and 0.0 to 0.17 with an average of 0.023 in well BR-3.

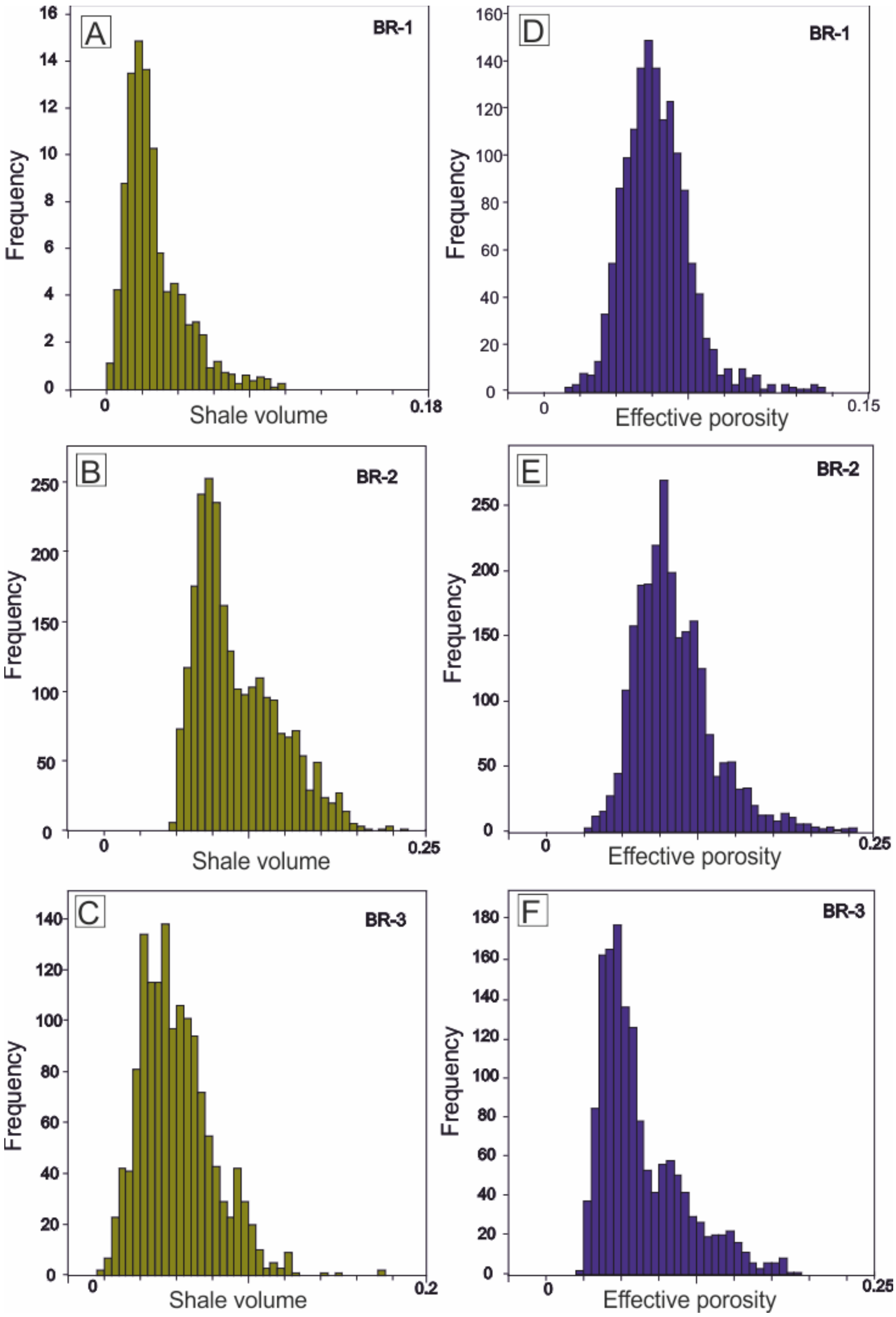

Figure 4: Histogram of the calculated shale volume and total porosity throughout the studied wells. a-c plots are shale volume consents in the Alan Formation were measured by old rock model. d-f plots are total porosity values derived from wireline log data.

Test operation was run for the drilled intervals of the Alan Formation while drilling progressing includes drilling stem test (DST). The test results show producing different fluid types within the limestone beds of Alan Formation, Figure (5). In well BR-2 a number of tests were run consequently for the Alan Formation interval. DST2 provided recovering of 2000 bbl/d of formation water, film of oil and hydrogen sulfide gas. DST3 was recorded only 965 bbl/d of recovered fluids including drilling mud (96%) and crude oil (4%). The fluid recovered in DST5 was 750 bbl/d that contain formation water (98%), crude oil (1%) and solid content (1%). The last test for this interval was DST6 that was recorded about 792bbl/d composed of formation water (90%), crude oil (9%) and solid content (1%). Furthermore, the DST results for well BR-1 and BR-2 have provided a weak oil show with solid content in drilling mud fluid.

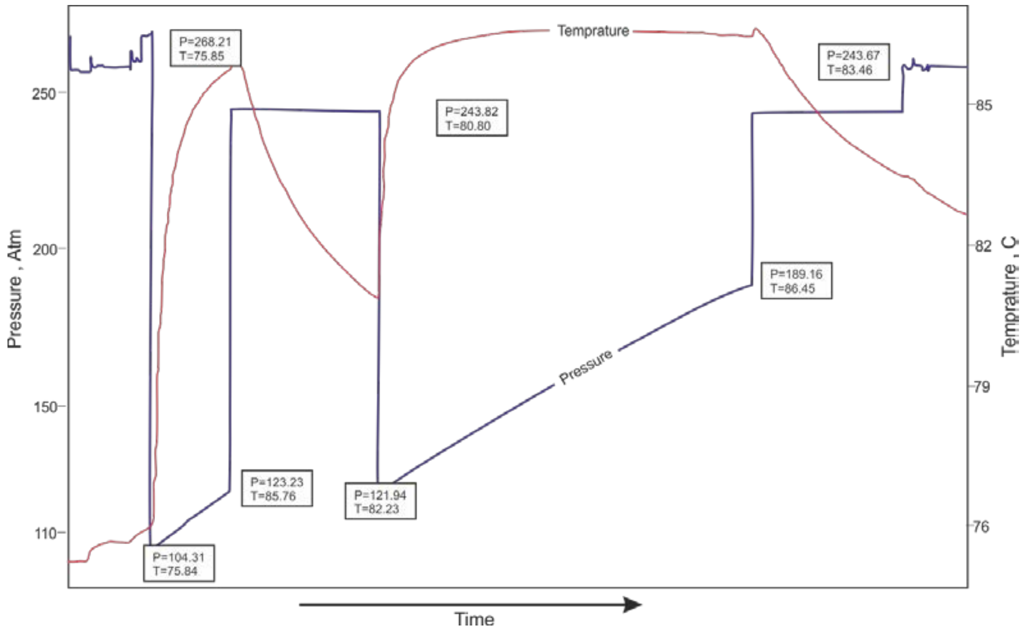

Figure 5: Drilling stem test (DST) was run in drilled interval of the Jurassic Alan Formation in well BR-2.

The carbonate beds of the Early Jurassic Alan Formation are slightly argillaceous and chalky limestone. Despite of low shale content, qualitatively these beds do not yield reservoir potential throughout the studied wells. No macro porosity and micro porosity have been observed during core sample description; however, several fractures were observed which possibly provide an unknown amount of open and connected porosity. In contrast, the intercalation of the limestone beds of the formation with shale beds at the top and with anhydrite beds from middle to the bottom of the formation was destroyed matrix porosity and reduced the impaction of fracture distribution on reservoir quality and terminated the fluid path way connectivity within the limestone beds.

The wireline log cross plots clearly provide that the limestone beds of the Alan Formation have tight reservoir properties, Figure (6). The plotted data have fallen on the lower part of the limestone line and commonly smaller than 10% of apparent porosity. The scattering of the plotted raw data is related to anhydrite and shale minerals in the limestone beds especially for the density log reading which is very sensitive to matrix and grain density variations. The similarity between results of the N-D and N-S plots refers to the fact that the pores in the limestone beds are dominantly primary origin and these pores has been destroyed by compaction, cementation and dewatering.

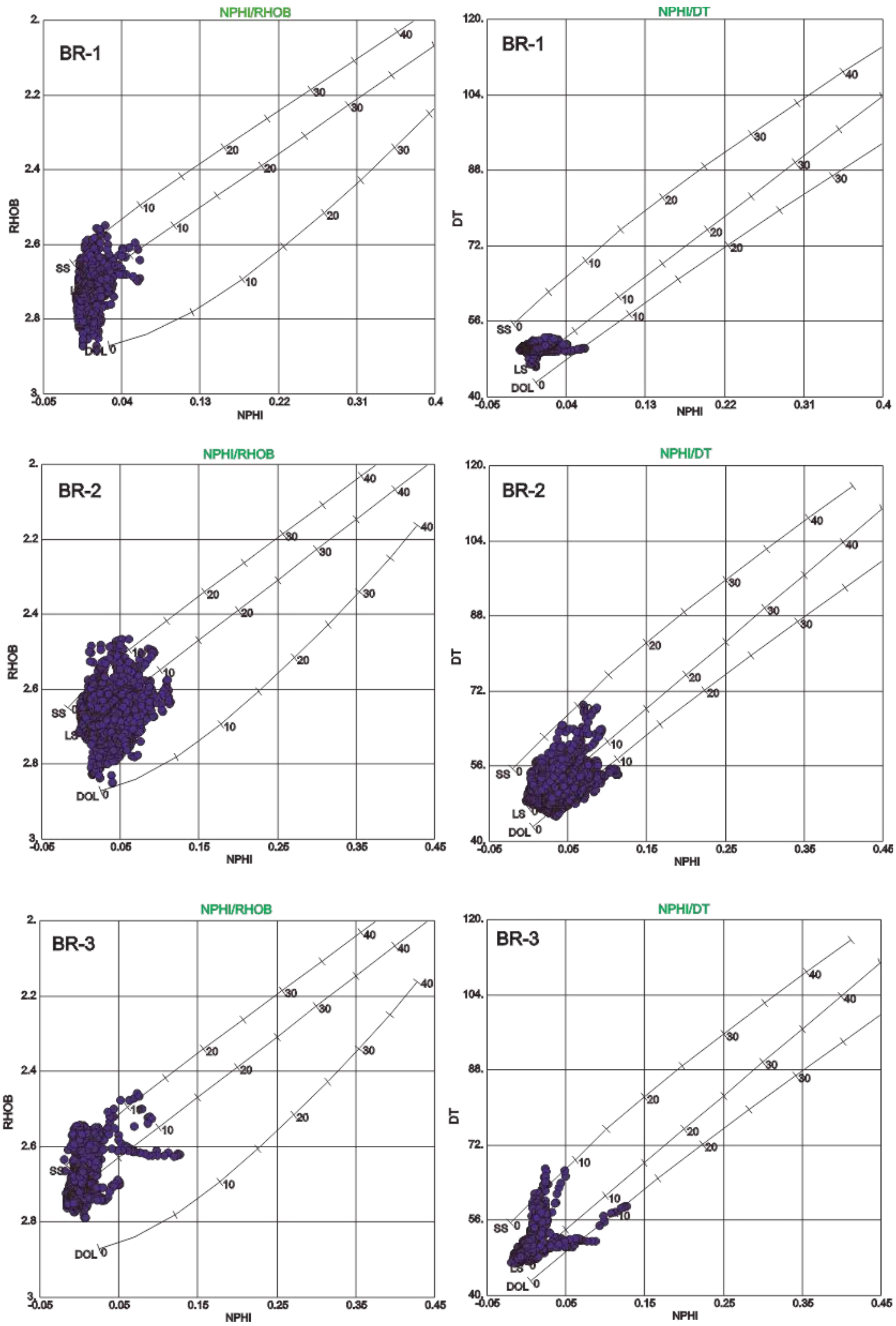

Figure 6: Wireline log data cross plots. Neutron-Density and Neutron-Sonic cross plots for the Alan Formation in the Barda Rash field.

The early Jurassic Alan Formation is located in the oil bearing zones of the Jurassic petroleum system in the Barda Rash field [21, 22, 23]. The resistivity log in the un-invaded zone (LLD) shows high resistivity reading (LLD>50 ohm.m) which is probably indicator for oil bearing intervals or the phenomena is related to anhydrite matrix distribution on the rock mass of the formation Figure (7). The fluid recovery test results achieved from the drilling stem tests (DST) shown limited amount of oil flow throughout the wells. As a result, high reading of the resistivity logs in the virgin zone are corresponded to the anhydrite rock type intervals [37]. Furthermore, resistivity fluctuations were recorded by the MSFL from the flushed zone of the same intervals.

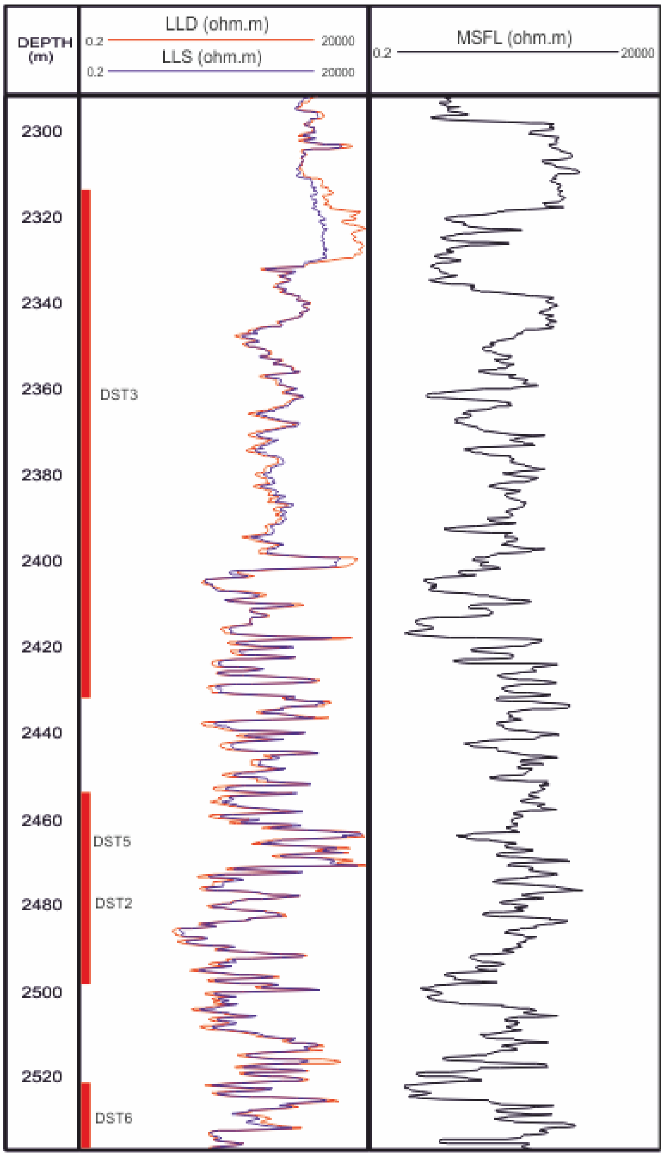

Figure 7: Resistivity logs of Alan Formation in well BR-2, Barda Rash field. The resistivity logs are including Deep Laterolog (LLD) of un-invaided zone, Shallow Laterolog (LLS) of transition zone and MicroSpherically focused log (MSFL) of flushed zone.

The buckle plot was drawn between the calculated water saturation and total porosity achieved from wireline log data for understanding the formation water mobility for the flow tested intervals, Figure (8). However, the magnitude of the porosity is not yield multiphase fluid flow productivity and the dominant produced fluid is expected to be the formation water. The residual water still can be seen from the plotted buckle figures as the plotted data was fallen to the similar line that represent a non-movable water trapped within nano-scale pores [7,38 and 39] and the movable water data have scattered distribution on the figure.

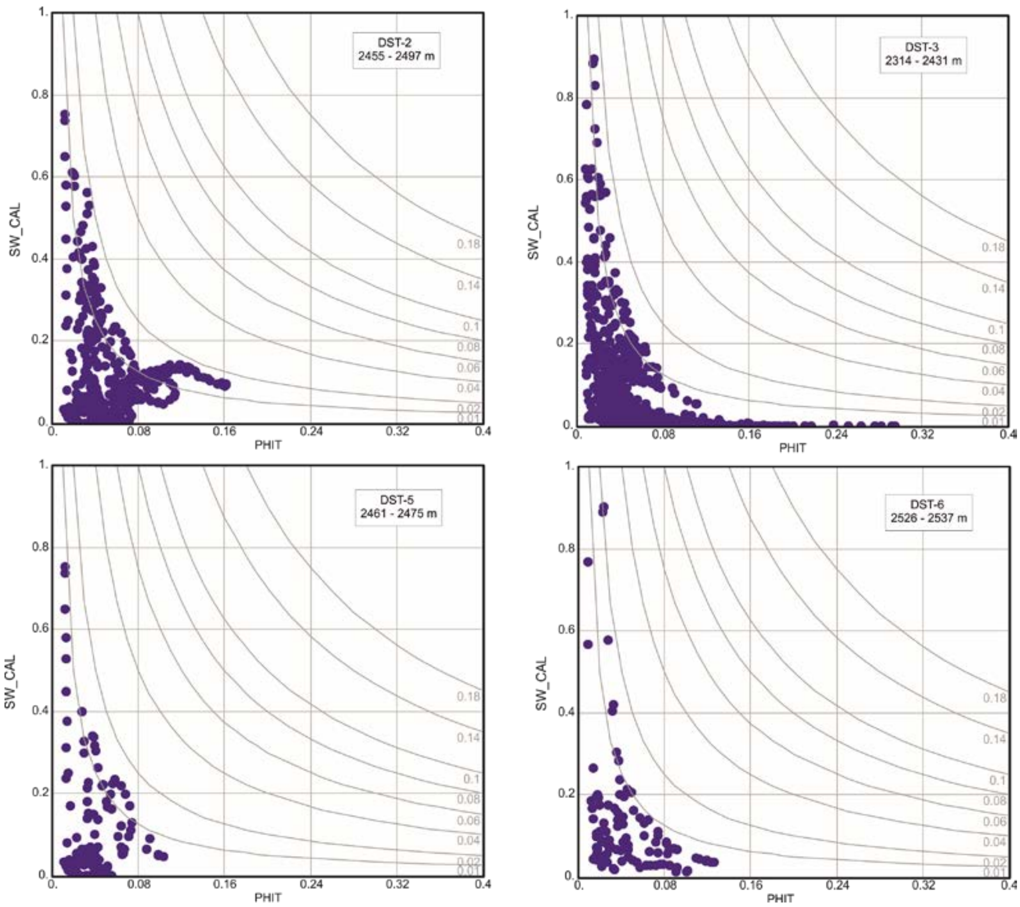

Figure 8: Buckles plots are drawn between the log derived porosity and calculated water saturation for Alan Formation in well BR-2, Barda Rash field. The plotted intervals were chosen based on drilling stem test intervals of the same intervals.

The wireline log analysis was not given a potential sign from the resistivity logs for oil and water zones availability throughout the drilled interval of the Early Jurassic Alan Formation, but the DST results were recorded the maximum volume of oil fluid as 5% to 9% while the other amounts are presented by formation water and drilling fluid. The fluid flow tests do not give a commercial result for the volume of the reserved hydrocarbon in this interval for the early stage exploration in this field. This formation with the obtained petrophysical outputs and observed reservoir characterisation possibly has source rock behavior rather than to be acted as a reservoir rocks. However, acidisation of the oil bearing intervals probably improve fracture aperture and consequently enhances the fluid movability and recovery of the available hydrocarbon in the early stage of development of the field or hydraulic fracturing can be considered as an alternative technique for enhancing fluid recovery throughout the Jurassic formation in the Barda Rash field.

5. CONCLUSION

The dominant conclusions of the reservoir characterisation investigation and hydrocarbon movability study the Early Jurassic Alan Formation in Barda Rash field from the wireline log analysis, rock description and test results are as follows:

- The Alan Formation consist of the heterogeneous limestone beds intercalated with shale layers in the upper parts and anhydrite beds in the middle and lower part throughout the studied wells. The shale contents and anhydrite beds are negatively impacted on the reservoir quality of the formation.
- The limestone beds are characterised by lack of visible pore types and macro pores cannot be observed within the cored intervals. Furthermore, the primary and secondary pores occluded by secondary minerals. In addition, the fracture surfaces filled with anhydrite, shale and calcite and eventually the reservoir fluid flow connection has been destroyed.
- The magnitude of the effective porosity is started from 0.0 of the anhydrite layers to 0.18 of the limestone beds with an average of 0.026. The quantity of the available porosity is not enough to qualify the formation as a potential reservoir rocks within the Jurassic petroleum system. In contrast, similar to the other carbonate rocks in the Zagros basin this formation is considered as tight carbonate reservoir rock and has very limited amount of producible hydrocarbon.
- The fluid distribution throughout the drilled interval of the formation from the resistivity wireline log analysis has been identified as oil bearing interval specifically upper part of the formation. However, the drilling stem test result shown very limited amount of recordable hydrocarbon which indicate low matrix permeability and weak fracture interconnection network.

ACKNOWLEDGEMENT

The raw data of this study was provided by Komet Group S.A. Operation Company. I would like to thank the operation staffs from the company in Barda Rash field.

REFERENCE

[1] G. H. Sherwani, and H. A. Zangana, Reservoir Characterization of Early Jurassic Formations in Selected Wells in the Duhok Governorate, Iraqi Kurdistan Region. Journal of Science and Engineering, 1(1), 11-18, 2017.

[2] B. Al-Qayim and F. Rashid, Reservoir Characteristics of the Albian Upper Qamchuqa Formation Carbonates, Taq Taq Oilfield, Kurdistan, Iraq. Journal of Petroleum Geology, 35, 317-341, 2012.

[3] F. Rashid, P.W.J. Glover, P. Lorinczi, R. Collier, and J. Lawrence, , Porosity and permeability of tight carbonate reservoir rocks in the north of Iraq. Journal of Petroleum Science and Engineering, 133, 147-161,2015a.

[4] F. Rashid, P.W.J. Glover, P. Lorinczi, , D. Hussein, , R. Collier, and J. Lawrence, Permeability prediction in tight carbonate rocks using capillary pressure measurements, Marine and Petroleum Geology, 68, 536-550, 2015b.

[5] F. Rashid, P.W.J. Glover, P. Lorinczi, D. Hussein, and J. Lawrence, Microstructural controls on reservoir quality in tight oil carbonate reservoir rocks. Journal of Petroleum Science and Engineering, 156, 814-826, 2017.

[6] B, Al-Qayim, and D. Othman, Reservoir characterization of an intra-orogenic carbonates platform: Pila Spi Formation, Taq Taq oil field, Kurdistan, Iraq. Geological Society, London, Special Publications, 370, 139-168, 2012.

[7] D. Hussein, J. Lawrence, F. Rashid, P. Glover, and P. Lorinczi, Developing pore size distribution models in heterogeneous carbonates using especially nuclear magnetic resonance. In Engineering in Chalk: Proceedings of the Chalk 2018 Conference (pp. 529-534). ICE Publishing, 2018.

[8] A.A.M. Aqrawi, J.C. Goff, A.D. Horbury, F.N. Sadooni, The Petroleum Geology of Iraq. Scientific Press, Beaconsfield, 424, 2010.

[9] T.K. Al-Ameri and J. Zumberge, Middle and Upper Jurassic hydrocarbon potential of the Zagros Fold Belt, North Iraq. Marine and Petroleum Geology, 36, 13-34, 2012.

[10] F. Rashid, D. Hussein, J.A. Lawrence, and P. Khanaqa, Characterization and impact on reservoir quality of fractures in the cretaceous Qamchuqa Formation, Zagros folded belt. Marine and Petroleum Geology,

113,104-117, 2020.
[11] R.A. Abdula, Organic geochemical assessment of Jurassic potential source rock from Zab-1 well, Iraqi Kurdistan, Iraqi Bulletin of Geology and Mining, 12(3), 53 – 64, 2016.
[12] W.S. El Diasty, S.Y. El Beialy , A.Q. Mahdi and K.E. Peters, Geochemical characterization of source rocks and oils from northern Iraq: Insights from biomarker and stable carbon isotope investigations. Marine and petroleum geology, 77, 1140-1162, 2016.
[13] M.H. Hakimi, A.A. Najaf, R. A. Abdula and I. M.J.Mohialdeen, Generation and expulsion history of oil-source rock (Middle Jurassic Sargelu Formation) in the Kurdistan of north Iraq, Zagros folded belt: Implications from 1D basin modeling study. Marine and petroleum geology, 162, 852–872, 2018.
[14] Ryder Scott Company Estimated unrisked discovered and undiscovered total petroleum initially in place attributable to certain interests in the Shaikan License Block, Kurdistan, Iraq. Report prepared for Gulf Keystone Petroleum Ltd, 2011.
[15] D. S. Mackertich, and A. I. Samarrai, History of hydrocarbon exploration in the Kurdistan Region of Iraq. GeoArabia, 20(2), 181-220, 2015.
[16] A. Law, D. Munn, A. Symms, D. ,Wilson, S. Hattingh, R. Boblecki, K. , Al Marei, P. Chernik, D. Parry and J. Ho , Competent person's report on certain petroleum interests of Gulf Keystone Petroleum and its subsidiaries in Kurdistan, Iraq. ERC Equipoise Ltd, 114, 2014.
[17] K. A. Mustafa, Geochemical and microfacies analysis of some liassic Formations in selected sections, Kurdistan, northern Iraq, unpublished M.Sc thesis, p. 105, University of Bergen, 2009.
[18] I. M. J. Mohialdeen, Hydrocarbon generation potential and palynological study of the early jurassic succession (Alan, Mus, and Adaiyah Formations) in well Miran-2, sulaimaniyah, kurdistan region, iraq. Iraqi Bulletin of Geology and Mining, 14(1), 13-30, 2017.
[19] M. S . Ameen, Possible forced folding in the Taurus-Zagros Belt of Northern Iraq , Geol Mag 128 (6) ,561-584,1991.
[20] S.Z. Jassim and J.C. Goff, The Geology of Iraq. Dolin, Prague, p. 341, 2006.
[21] M. M. Zebari, and C. M. Burberry, 4-D evolution of anticlines and implications for hydrocarbon exploration within the Zagros Fold-Thrust Belt, Kurdistan Region, Iraq. GeoArabia; Gulf PetroLink, Bahrain, 20, 161-188, 2015.
[22] Komet Group S.A., Geological report on the complete drilling, well Barda Rash number 1, Barda Rash block, Kurdistan region of Iraq, 2009.
[23] Komet Group S.A., Geological report on the complete drilling, well Barda Rash number 2, Barda Rash block, Kurdistan region of Iraq, 2010.
[24] Komet Group S.A. , Geological report on the complete drilling, well Barda Rash number 3, Barda Rash block, Kurdistan region of Iraq,2011.
[25] D. V. Ellis, and J. M. Singer, Well logging for earth scientists. Dordrecht: Netherlands Springer, 2nd edition, 692, 2007.
[26] G. Asquith, and D. Krygowski, Basic well log analysis, Tulsa, Oklahoma AAPG, 225, 2004.
[27] V. K. Sissakian, Geological map of Arbeel and Mahabad quadrangles, sheet NJ-38-13, 1/250000. Baghdad, Iraq: State establishment of geological survey and mining, 1997.
[28] V. K. Sissakian, D.H. Hagopian, and E. A. Hasan, Geological map of the Al-Mousl quadrangle, sheet NJ-38-14 and NJ-38-15, 1/250000. Baghdad, Iraq: State establishment of geological survey and mining, 1995.
[29] M. H. Rider, and M. Kenedy, The geological interpretation of well logs, Sutherland, Rider-French Consulting Ltd, 440, 2011.
[30] K. E. Dahlberg, A practical model for analysis of compensated neutron logs in complex formations. SPWLA Annual Logging Symposium, Denver,1989.
[31] J. Fanchi, Integrated reservoir asset management, Burlington, USA, Gulf professional publishing is an imprint of Elsevier, 2010.
[32] K. Bhuyan, and Q. R. Passey, Clay estimation from gamma ray and neutron-density porosity logs. SPWLA, 35th annual logging symposium, 1994
[33] Schlumberger, Definition of porosity: How porosity is measured. Oil field review, 2012.
[34] R. C. Van Bellen, H. V. Dunnington, R. Wetzel, and D. M. Morton, Lexique Stratigraphique International: 03 10 Asie (Iraq). Paris: Centre National de la Recherche Scientifique,1959 (Reprinted by Gulfpetro Link, 2005).
[35] T. Buday, The Regional Geology of Iraq .V.L.; Stratigraphy and Paleogeography, Baghdad, S.O.M. Library, 445, 1980.
[36] R. Wiley, and J. G. Pachett, CNL (Compensated Neutron Log) neutron porosity modeling, a step forward. SPWLA 30th Annual Logging Symposium, June 11–14, 1989, Paper O O., 31, 1990.
[37] F. Ma, W. Yang, Y. Zhang, H. Li, M. Xie, X. Sun and Y. Wang Bai, Characterization of the reservoir-cap rock of the large basement reservoir in the Dongping field, Qaidam Basin, China. Energy Exploration and Exploitation, 36(6), 1498–1518, 2018.
[38] D. Hussein, R. Collier, J. Lawrence, F. Rashid, P.W.J. Glover, P. Lorinczi, and D.H. Baban, Stratigraphic correlation and paleoenvironmental analysis of the hydrocarbon-bearing Early Miocene Euphrates and Jeribe formations in the Zagros folded thrust-belt. Arabian Journal of Geosciences 10:543, 2017.
[39] F. Rashid, D. O. Hussein and H.A. Zangana , Petrophysical Investigation of the Khurmala Formation in Taq Taq Oil Field, Zagros Folded Belt. ARO-THE SCIENTIFIC JOURNAL OF KOYA UNIVERSITY, 8(1), 5-16, 2020.