Journal Homepage: http://ijcpe.uobaghdad.edu.iq
Iraqi Journal of Chemical and Petroleum Engineering
Vol. 25 No. 4 (December 2024) 139 – 145
EISSN: 2618-0707, PISSN: 1997-4884

Identification of clay mineral compounds in the Southern Iraqi upper Nahr Umar Formation using SGR logging

Mahdi M. Kadhim [a, b, *], Hassan A. Abdul Hussein [a], Atheer Dheyauldeen [c]

a Petroleum Engineering Department, College of Engineering, University of Baghdad, Baghdad, Iraq
b Thi Qar Oil Company, Ministry of Oil, Thi Qar, Iraq
c School of Minerals and Energy Resources Engineering, University of New South Wales, Sydney, New South Wales 2052, Australia

Abstract

Typically, sandstone oil reserves comprise various clay minerals, such as illite, chlorite, and kaolinite. The existence of these clay minerals drastically affected the quality of these reservoirs. This paper attempts to detect clay minerals and environmental deposition of the upper shaly-sand unit (USSU) of the Nahr Umar formation, as it is the main reservoir. It is a portion of an anticline composed of a lower Cretaceous clastic sandstone formation. The kind of environment, clay minerals, and depositional correlation between total organic matter and uranium content were determined using a spectral log of gamma-ray (SGR). According to the SGR log, the primary constituents of USSU are mixed-layer clays, which are illite, kaolinite, and chlorite. The investigated wells in the field's western north have Th/U (thorium/ uranium) ratios ranging from 0.465 to 18.4. Based on the Th/U ratio, the USSU had a mostly shallow marine with continental and marine environment traces. Additionally, a Th/K (thorium /potassium) cross-plot revealed that as kaolinite decreased, illite increased in the formation's southern region.

Keywords: SGR; clay minerals; sedimentary conditions; Nahr Umar formation; organic materials; shaly-sand formation; Kaolinite.

Received on 10/02/2024, Received in Revised Form on 06/04/2024, Accepted on 06/04/2024, Published on 30/12/2024

https://doi.org/10.31699/IJCPE.2024.4.13

1- Introduction

Clay minerals are critical in essential areas of petroleum engineering, especially in producing and exploring hydrocarbons. By expanding or contracting, they alter the reservoir rock's porosity, permeability, and general quality, necessitating a careful evaluation of reservoir characterization. They result in formation damage during reservoir fluid flow, which lowers permeability and highlights the necessity of precise reservoir modeling. Clays provide difficulties during drilling operations, such as wellbore instability and higher drilling fluid viscosity, necessitating cautious fluid and additive selection [1]. Clay swelling close to the wellbore can reduce productivity during the completion and production stages, requiring methods like chemical treatments and hydraulic fracturing [2]. Moreover, identifying clay minerals is crucial for extracting hydrocarbons in several petroleum engineering fields, providing insights into depositional settings and supporting reservoir characterization and modeling [3]. Sandstone characteristics, such as natural radioactivity, porosity, density, permeability, water content, electrical conductivity, and reactivity to enhanced oil production techniques, are greatly influenced by clay minerals' quantity, distribution pattern, and morphology [4, 5, 6]. The naturally occurring isotopes potassium (40K), uranium (238U, 234U, 235U), thorium (232Th), and the byproducts of their disintegration are the sources of the radioactivity found in rocks. Geological processes carry these isotopes, originally mostly found in acidic igneous rocks, to the sediments, which often aggregate in a clayey material. Natural radiation is a significant lithological indication easily acquired by geophysical techniques [7, 8].

The high gamma-ray response often denotes the existence of fine-grained deposits or rich in clay rock formations such as mudstone, claystone, and shale. Meanwhile, comparatively low gamma radiation typically indicates the presence of carbonate rock and coarse-grained sandstone [9, 10]. Since the radiation background comes from non-clay rock elements, this can cause overreading of clay content values. Usually, gamma-ray logs readings record the total natural radioactivity of the isotopes mentioned above (thorium, potassium, and uranium) and the products of their decay, which may result in an inaccurate assessment of the reservoir characteristics of the analyzed rock layer [11, 12].

Natural gamma-ray logs are less good at revealing geologic conditions than spectral gamma-ray (SGR) recordings in sedimentary sequences [13]. The three most prevalent naturally occurring radioisotopes—uranium, thorium, and potassium—can be estimated using SGR logging. Sedimentary rocks include minor

*Corresponding Author: Email: mahdi.jawad2208m@coeng.uobaghdad.edu.iq

amounts of uranium and thorium, although potassium is probably their most prevalent [14,15].

Many studies have successfully characterized the mineralogy and sedimentation of subsurface formations using SGR [16,17]. The presence of uranium in the formations reflects the total amount of organic matter. At the same time, the concentration of potassium and thorium measured by SGR helped identify clay minerals and depositional conditions [18,19,20].

In this study, the upper portion of the Nahr Umar formation with shaly-sand formation was discretized and recognized using SGR logs. The clay mineral compounds and depositional environment were also identified, and the discrepancy between the SGR log and the natural gamma ray log was noted.

2- Area of study

The oil field is located in southern Iraq, southeast of Nasiriyah City, and 12 km north of the Luhais oil field. This is seen in Fig. 1. The oil field is around 7 km wide and 30 km long. As seen in Fig.1, one of the most prolific reservoirs in southern Iraqi fields is thought to be the Nahr Umr formation, which has a prominent place in the Late Cretaceous Albia Nahr-Umar stratigraphic column as illustrated by Fig. 1 [21, 22]. The smaller dome is south of the Nahr Umar formation, and the giant dome is located in the northern portion of the field. The saddles are shallow in both domes.

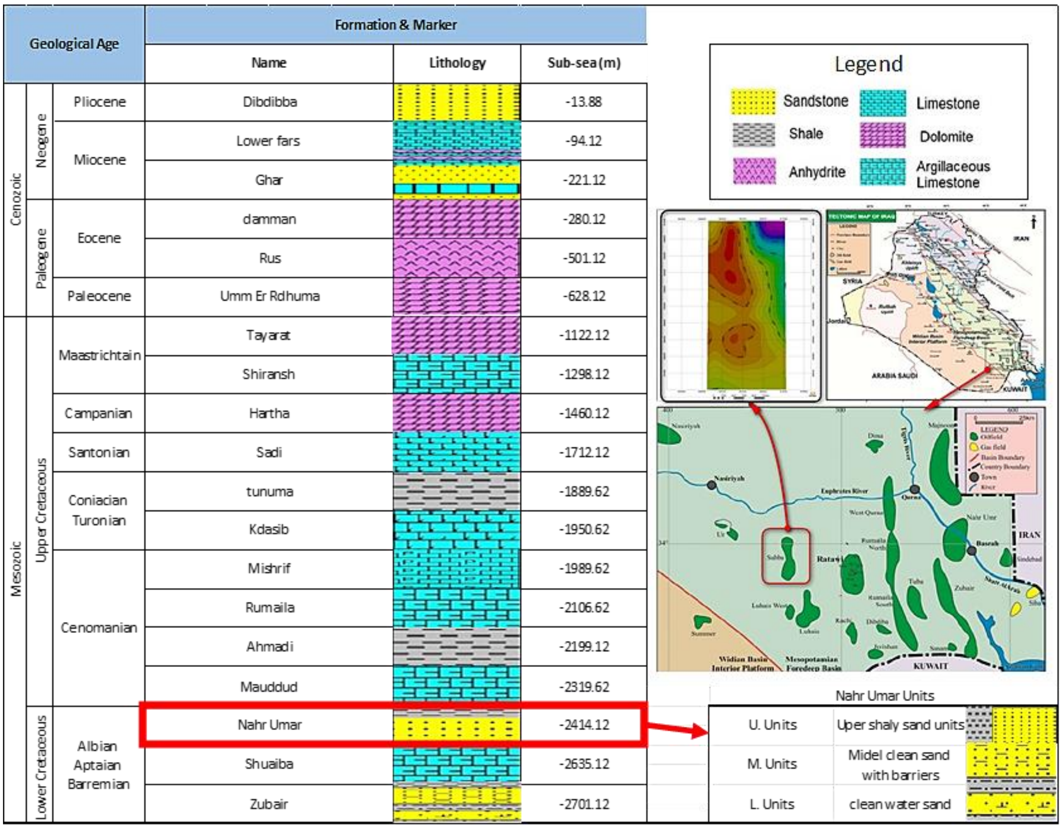


Fig. 1. Stratigraphic column for studied oil filed, modified after [18]

The shale, sand, and limestone comprise the bedrock of the Nahr Umar reservoir [23]. The thickness of the formation varies from 209 to 236 meters over the reservoir's length. As the percentage of limestone rocks rises and the number of shale rocks grows in the south, the thickness decreases toward the north. Within the reservoir are several reservoir units. The top, or most major, unit B11, mostly made up of shale rocks with some limestone rocks mixed in, will be the focus of the inquiry. It also contains thin, reservoir-insignificant sand layers that reach a thickness of 70.5 m.

3- Methods

The first interpretation of the SGR log in the upper shaly sand unit (USSU) or B11, according to the Ministry of Oil zonation for Nahr Umar formation, is sedimentary environments. This analysis depends on logs data run in two wells located in the north dome and no recording of SGR in the south dome (W-10, W-16) as well as the first well with missing data of 31.4 m from the total thickness of USSU 74.8 m. An Iraqi oil national company recorded Both wells at the end of the eighties of the last century. The SGR data identify different minerals' high K, Th, and U contents. The Th/K cross-plot simplifies the identification of clay, sands, various kinds of heavy minerals, and shales. By determining their association, many cross-plots are utilized to determine the minerals in clay. The recorded data of both wells do not include a photoelectric log (Pe), so the cross plots with Pe are not directly available.

4- Results and discussion

4.1. Thorium (Th) and potassium (K) ratio

To distinguish mica from K-feldspar and recognize clay minerals, the potassium (K) versus thorium (Th) cross-plot was constructed, as shown in Fig. 2. The amount of shale and other types of clays in the formation was identified using the ratio of thorium to potassium (Th/K) and another method that involved graphing the quantities of thorium against potassium [24]. Th in parts per million and K in percentages are utilized to get the ratio values, as shown in Table 1 and Table 2 for the wells W-10 and W-16 of USSU, respectively.

Table 1. SGR log data for Well W-10 with Th/K and Th/U ratio

USSU	SGR	CGR	U (ppm)	K (%)	Th (ppm)	TPR	TUR	UPR
Average	61.69	47.86	1.53	1.08	8.89	16.63	5.75	4.26
Max	127.03	104.77	5.26	2.85	19.88	120.83	17.54	52.76
Min	10.59	9.41	0.02	0.04	1.47	4.69	0.70	0.64

Differences in clay mineral assemblages can explain the variation in Th/K ratios within and between them. Low Th/K ratios are associated with clay-mineral ensembles dominated by Illite, whereas high Th/K ratios are associated with clay-mineral suites dominated by Kaolinite.

The limit cutoff of lines separated between clay minerals are listed in Table 3 as shown below from 0.6 for feldspars to ratio upper to 10 referred to Kaolinite and chlorite.

Table 2. SGR log data for Well W-16 with Th/K and Th/U ratio

USSU	SGR	CGR	U (ppm)	K (%)	Th (ppm)	TPR	TUR	UPR
Average	51.45	27.55	2.99	1.40	14.09	6.89	2.71	3.43
Max	98.08	66.27	5.74	12.95	159.18	41.15	18.4	28.18
Min	23.34	5.10	0.14	0.12	1.19	0.42	0.23	0.11

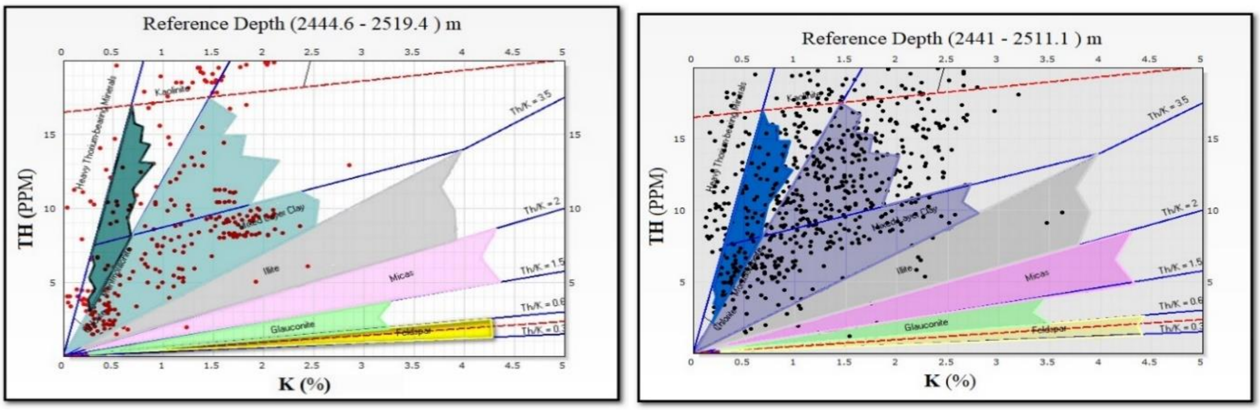
Table 3. Ratio TH/K (ppm/%) classification based for clay minerals [4]

No	Th/k (ppm/%)	Minerals
1	< 0.6	Feldspars
2	0.6 - 1.5	Glauconite
3	1.5 - 2	Micas
4	2 - 3.5	Illite
5	3.5 - 10	Mixed-layer clays
6	> 10	Kaolinite and chlorite

The data are plotted for both wells as a cross-plot between the Th versus K. Generally, the results showed that the USSU is mainly composed of mixed-layer clays, Kaolinite, and Illite. In addition, the Illite increased south towards the field with decreasing Kaolinite and chlorite, which means that the K increased in the southern part of USSU, as shown in Fig. 2 a and Fig. 2 b; Fig. 3 a and Fig. 3 b.

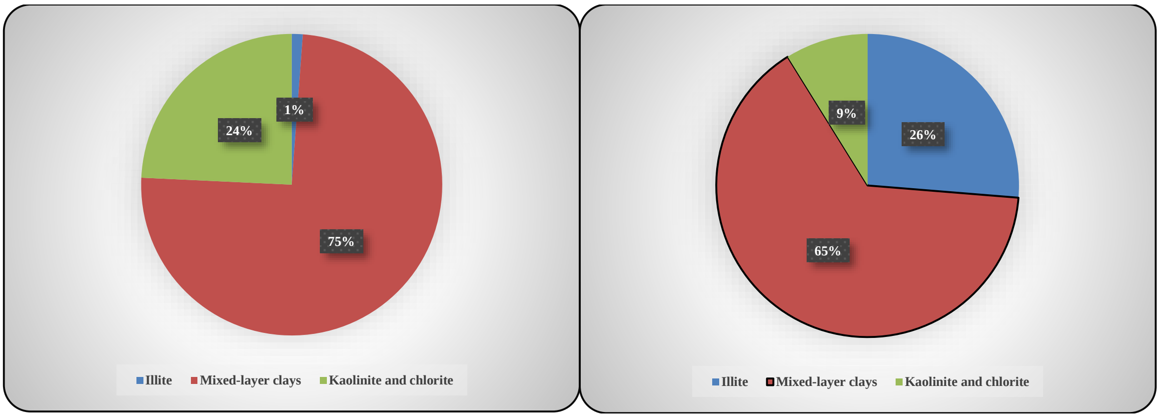
4.2. Th/U and depositional environment

The thorium/uranium relationship was used to detect the sort of environment that would be discovered, with a high ratio suggesting a continental environment while a low ratio suggesting a marine environment [24,25]. Thus, the distinction between the concentrations of Th and U indicates whether the influence is more continental or marine. The Th/U ratio may be used to categorize the sedimentary facies into three groups: low 2, which indicates a marine environment; between 2 to 7, which indicates the conditions of shallow marine; and above > 7, which indicates continental deposits [26]. The use of SGR for Th and Uran cross plot through USSU is shown in Fig. 4 a and Fig. 4 b, where the deposit conditions appear mostly as shallow marine deposits with little equal percent of marine and continental deposits for both wells.



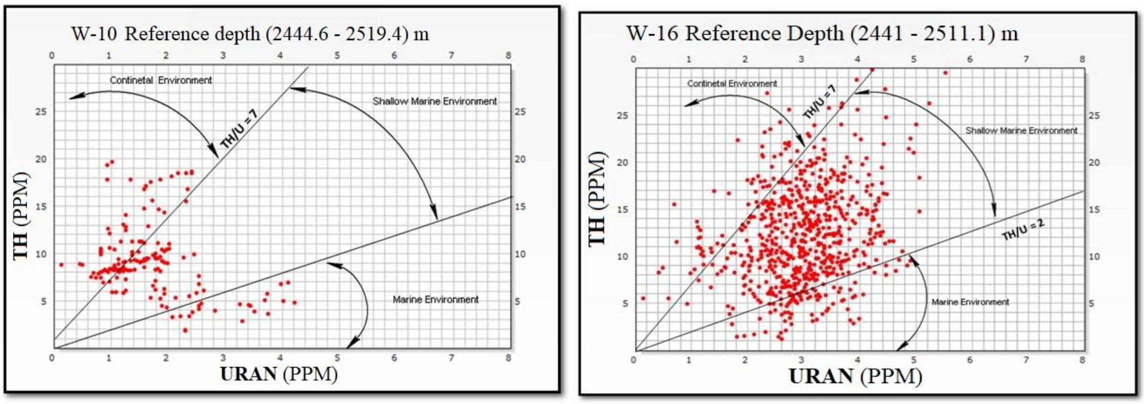
(a) (b)

Fig. 2. Th/K cross-plot of USSU a) Well W-10; b) Well W-16



(a) (b)

Fig. 3. Main Clay Minerals a) Well W-10; b) Well W-16



(a) (b)

Fig. 4. Th-Uran cross-plot to USSU A) Well W-10, B) Well W-16

Plotting of all the SGR Log's recorded variables across the USSU Log Track revealed that the layer is composed of sand and shale at different depths. Up to a depth of 2495 meters, the ratio of TH/K indicates that most of the clay components are mixed-clay layers. At this point in the layer, a rise in TH/K is noted due to an increase in thorium and a reduction in potassium in both wells under study. Along with a continental environment, the TH/U ratio also revealed that most of the depositional environment is a shallow marine environment scattered with a marine environment.

The last track shows the ratio of uranium to potassium and thorium to uranium to determine the organic materials represented by the yellow shadow. This ratio increased with depth beginning at 2490m, which is why this layer reservoir became irrelevant, as seen in Fig. 5 and Fig. 6.

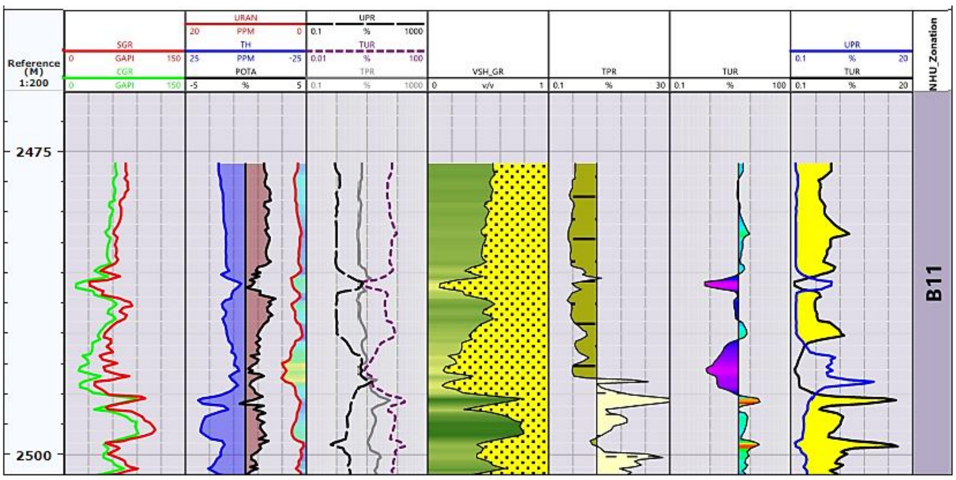


Fig. 5. SGR log interpretation of USSU for Well W-10

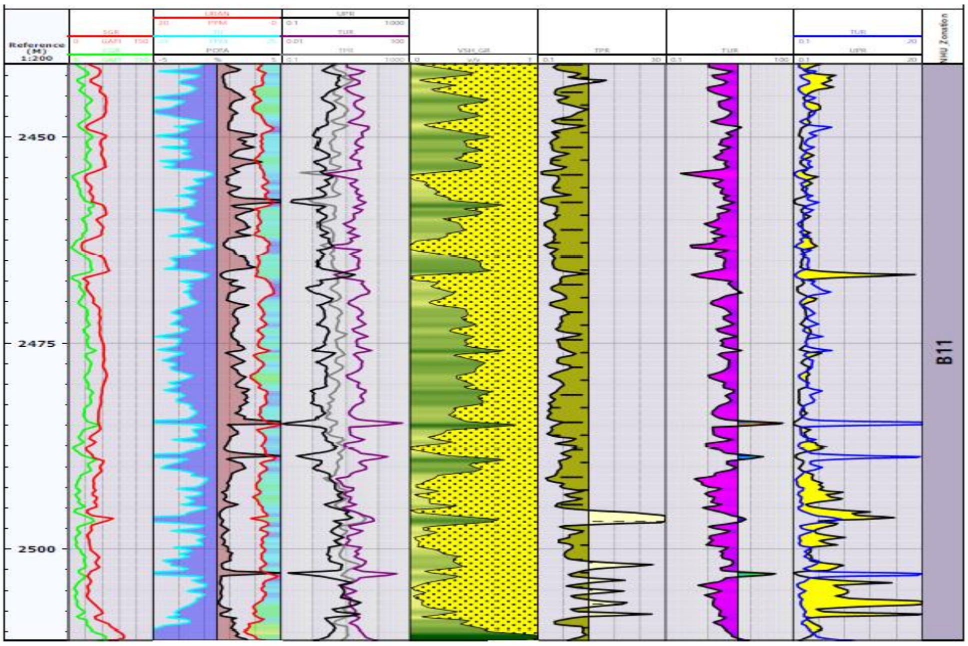


Fig. 6. SGR log interpretation of USSU for Well W-16

5- Conclusion

The gamma-ray spectroscopy log SGR was used in this work to conduct an in-depth examination of the USSU within the Nahr Umar Formation. The main conclusions were established using the following points:

1- The data cross-plot for identifying clay minerals was analyzed, and it was discovered that most of the clays are mixed-layer clays with traces of Kaolinite and some Illite.
2- Moving towards the field's southern dome, it was seen that the amount of Illite mineral has increased while the amount of Kaolinite mineral has decreased.
3- To validate the outcome of the preceding point, the SGR log preferred to run in the southern part of the field. For this reason, analyzing rock samples taken from the USSU is recommended.
4- It emerged that the USSU layer contains a small percentage of the marine and continental environments, with the shallow marine environment dominating.
5- It is evident from the investigation of organic components that the reservoir qualities in the north portion of the reservoir are better than those in the south portion.

Nomenclatures

K	Potassium
U	Uranium
Th	Thorium
SGR	Spectral-copy gamma ray
USSU	Upper shaly-sand unit
Pe	Photoelectric log
CGR	Computed gamma ray
TPR	Thorium Potassium ratio
TUR	Thorium Uranium ratio
UPR	Uranium Potassium ratio

References

[1] G. Konert, "The Petroleum Geology of Iraq," *Journal of Petroleum Geology*, vol. 33, no. 4, pp. 405–405, Sep. 2010, https://doi.org/10.1111/j.1747-5457.2010.00487.x

[2] A. Sanaei, M. Haddad, and K. Sepehrnoori, "Hydraulic Fracturing Fluid Effect on Clay Swelling and Water Blockage in Stimulated Naturally Fractured Reservoirs," *Proceedings of the 5th Unconventional Resources Technology Conference*, 2017, http://dx.doi.org/10.15530/urtec-2017-2697654

[3] I. D.O., O. O.C., A. M.T., O. T., and E. A., "The Role of Clay Minerals in Hydrocarbon Generation, Migration and Accumulation," *International Journal of Scientific & Engineering Research*, vol. 13, no. 09, pp. 1–24, Sep. 2022, http://dx.doi.org/10.14299/ijser.2022.09.01

[4] R. H. Worden and S. Morad, "Clay Minerals in Sandstones: Controls on Formation, Distribution and Evolution," *Clay Mineral Cements in Sandstones*, pp. 1–41, Oct. 1999, http://dx.doi.org/10.1002/9781444304336.ch1

[5] K. M. Ahmad, F. Kristaly, and R. Docs, "Effects of clay mineral and physico-chemical variables on sandstone rock permeability," *Journal of Oil, Gas and Petrochemical Sciences*, vol. 1, no. 1, pp. 18–26, Feb. 2018, http://dx.doi.org/10.30881/jogps.00006

[6] R. Wang, W. Shi, X. Xie, W. Zhang, S. Qin, K. Liu, and B. A. Busbey, "Clay mineral content, type, and their effects on pore throat structure and reservoir properties: Insight from the Permian tight sandstones in the Hangjinqi area, north Ordos Basin, China," *Marine and Petroleum Geology*, vol. 115, p. 104281, May 2020, http://dx.doi.org/10.1016/j.marpetgeo.2020.104281

[7] J. Klaja and L. Dudek, “Geological interpretation of spectral gamma ray (SGR) logging in selected boreholes,” *Nafta-Gaz*, vol. 72, no. 1, pp. 3–14, Jan. 2016,http://dx.doi.org/10.18668/ng2016.01.01

[8] Z. Liu, Y. Zhao, C. Colin, K. Stattegger, M. G. Wiesner, C. Huh, Y. Zhang, X. Li, P. Sompongchaiyakul, C. You, C. Huang, J. T. Liu, F. P. Siringan, K. P. Le, E. Sathiamurthy, W. S. Hantoro, J. Liu, S. Tuo, S. Zhao, S. Zhou, Z. He, Y. Wang, S. Bunsomboonsakul, and Y. Li, “Source-to-sink transport processes of fluvial sediments in the South China Sea,” *Earth-Science Reviews*, vol. 153, pp. 238–273, Feb. 2016, http://dx.doi.org/10.1016/j.earscirev.2015.08.005

[9] P.-Y. Chou, S.-M. Hsu, P.-J. Chen, J.-J. Lin, and H.-C. Lo, “Fractured-bedrock aquifer studies based on a descriptive statistics of well-logging data: A case study from the Dajia River basin, Taiwan,” *Acta Geophysica*, vol. 62, no. 3, pp. 564–584, Jan. 2014, http://dx.doi.org/10.2478/s11600-013-0187-0

[10] W. E. Ibrahim, A. M. A. Salim, and C. W. Sum, “Mineralogical investigation of fine clastic rocks from Central Sarawak, Malaysia,” *Journal of Petroleum Exploration and Production Technology*, vol. 10, no. 1, pp. 21–30, Aug. 2019, http://dx.doi.org/10.1007/s13202-019-00751-0

[11] W. H. Fertl, “Organic Carbon Content and Fractured Shale Reservoir Evaluation Based on Natural Gamma Ray Spectral Logging: ABSTRACT,” *AAPG Bulletin*, vol. 66, 1982.

[12] A. Omidpour, R. Moussavi-Harami, A. Mahboubi, and H. Rahimpour-Bonab, “Application of stable isotopes, trace elements and spectral gamma-ray log in resolving high-frequency stratigraphic sequences of a mixed carbonate-siliciclastic reservoirs,” *Marine and Petroleum Geology*, vol. 125, p. 104854, Mar. 2021, http://dx.doi.org/10.1016/j.marpetgeo.2020.104854

[13] F. J. Bataller, N. D. McDougall, and A. Moscariello, “Reviewing the correlation potential of Spectral Gamma Ray: a case study in Ordovician glacial environments in the Murzuq basin, SW Libya,” *Journal of African Earth Sciences*, vol. 188, p. 104475, Apr. 2022, http://dx.doi.org/10.1016/j.jafrearsci.2022.104475

[14] G. Byer, “Potential value of spectral gamma ray logging and data analysis to environmental applications of hydrofacies analysis and mass flux estimation,” *Symposium on the Application of Geophysics to Engineering and Environmental Problems 2021*, Jun. 2021, http://dx.doi.org/10.4133/sageep.33-028

[15] I. Guagliardi, D. Zuzolo, S. Albanese, A. Lima, P. Cerino, A. Pizzolante, M. Thiombane, B. V. De, and D. Cicchella, “Uranium, thorium and potassium insights on Campania region (Italy) soils: Sources patterns based on compositional data analysis and fractal model,” *Journal of Geochemical Exploration*, vol. 212, p. 106508, May 2020, http://dx.doi.org/10.1016/j.gexplo.2020.106508

[16] J. B. Svendsen and N. R. Hartley, “Comparison between outcrop-spectral gamma ray logging and whole rock geochemistry: implications for quantitative reservoir characterisation in continental sequences,” *Marine and Petroleum Geology*, vol. 18, no. 6, pp. 657–670, Jun. 2001, http://dx.doi.org/10.1016/s0264-8172(01)00022-8

[17] M. Ramkumar, R. Nagarajan, and M. Santosh, “Advances in sediment geochemistry and chemostratigraphy for reservoir characterization,” *Energy Geoscience*, vol. 2, no. 4, pp. 308–326, Oct. 2021, http://dx.doi.org/10.1016/j.engeos.2021.02.001

[18] M. K. Al-Jafar and M. H. Al-Jaberi, “Determination of clay minerals using gamma ray spectroscopy for the Zubair Formation in Southern Iraq,” *Journal of Petroleum Exploration and Production Technology*, vol. 12, no. 2, pp. 299–306, Dec. 2021, http://dx.doi.org/10.1007/s13202-021-01371-3

[19] D. A. Kozhevnikov, N. Ye. Lazutkina, and B. Yu. Melchuk, “Accuracy of spectral gamma-log interpretation models,” *IEEE Transactions on Nuclear Science*, vol. 42, no. 4, pp. 615–619, Aug. 1995, http://dx.doi.org/10.1109/23.467903

[20] Halliburton: Interpretation of the spectral gamma log. *Haliburton Ledger* 1995.

[21] A. K. Faraj and H. A. Abdul Hussein, “Vertical Stress Prediction for Zubair Oil Field/ Case Study,” *Journal of Engineering*, vol. 29, no. 2, pp. 137–152, Feb. 2023, http://dx.doi.org/10.31026/j.eng.2023.02.09

[22] A. A. Suhail, M. H. Hafiz, and F. S. Kadhim, “Petrophysical Properties of Nahr Umar Formation in Nasiriya Oil Field,” *Iraqi Journal of Chemical and Petroleum Engineering*, vol. 21, no. 3, pp. 9–18, Sep. 2020, http://dx.doi.org/10.31699/ijcpe.2020.3.2

[23] M. Hassan, A. Hossin, and A. Combaz, “Fundamentals of the differential gamma-ray log-interpretation technique,”. *In SPWLA 17th Annual Logging Symposium, Society of Petrophysicists and Well-Log Analyst*, Jan. 1976.

[24] M. S. Aljawad, A. A. Ali, and M. D. Abdulkhadim, “Comparison of Petrophysical Properties Measurement Methods in Sandston Rocks,” *Iraqi Journal of Chemical and Petroleum Engineering*, vol. 19, no. 2, pp. 15–20, Jun. 2018, http://dx.doi.org/10.31699/ijcpe.2018.2.3

[25] C. Degueldre and M. J. Joyce, “Evidence and uncertainty for uranium and thorium abundance: A review,” *Progress in Nuclear Energy*, vol. 124, p. 103299, Jun. 2020, http://dx.doi.org/10.1016/j.pnucene.2020.103299

[26] S. Adams and E. Charles , “Thorium-to-Uranium Ratios as Indicators of Sedimentary Processes: Example of Concept of Geochemical Facies,” *AAPG Bulletin*, vol. 42, 1958, http://dx.doi.org/10.1306/0bda5a89-16bd-11d7-8645000102c1865d

تحديد المركبات المعدنية الطينية في تكوين نهر عمر العلوي في جنوب العراق باستخدام تسجيل SGR

مهدي محمدجواد كاظم [١، ٢، *] ، حسن عبدالهادي عبدالحسين [١] ، اثير ضياء مهدي صالح ضياء الدين [٣]

١ قسم هندسة النفط، كلية الهندسة، جامعة بغداد، بغداد، العراق
٢ شركة نفط ذي قار، وزارة النفط، ذي قار، العراق
٣ كلية هندسة المعادن وموارد الطاقة، جامعة نيو ساوث ويلز، سيدني، نيو ساوث ويلز ٢٠٥٢، أستراليا

الخلاصة

المعادن الطينية تمثل أحد المكونات الأساسية للمكامن الرملية وتشمل الإليت، الكاولينيت، والكلوريت. تتأثر المواصفات المكمنية المهمة بتواجد تلك المعادن. الوحدة المكمنية الرملية العليا التي يتخللها الطفل والتي تعتبر من المكامن الرئيسية في حقل الدراسة. وهو جزء من الطية المحدبة التي ترسبت في العصر الطباشيري ألسفلي. تم تحديد نوع المعادن الطينية والبيئة الترسيبية وكذلك استخدام الارتباط بين المواد العضوية وتواجد اليورانيوم باستخدام البيانات المتحصلة من مجس اشعة كاما الطيفي (SGR). وفقاً لتحليل تلك البيانات وجد ان الطين ذو الطبقات المختلطة هو النوع السائد بالإضافة الى وجود الإليت، الكاولينيت، والكلوريت بنسب مختلفة. ان الابار تحت الدراسة والتي تقع في الشمال الغربي للحقل لديها نسب Th/U تتراوح من ٠,٤٦٥ إلى ١٨,٤ . من خلال استخدام نسبة Th/U تبين ان البيئة البحرية الضحلة هي البيئة السائدة مع وجود الطابع البيئي القاري والبحري، بالإضافة الى ذلك بين مخطط Th/K زيادة معدن الإليت على حساب نقصان في نسبة الكاولينيت كلما اتجهنا جنوباً.

الكلمات الدالة: تسجيل أشعة جاما الطيفية، المعادن الطينية، الظروف الترسيبية، تكوين نهر عمر، المواد العضوية، تكوين Shaly–sand، الكاولينيت.