International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 30 No. 1 Jul. 2020, pp. 162-173

http://www.ijias.issr-journals.org/

Petrographic characterization of Campanian sandstones in the Termit basin (Niger): Diagenetic implication on the reservoir quality

Neino Abdoulaye Garba[1], Kouakou Alphonse Yao[1], Moussa Harouna[2], and Isaac Fea[3]

[1]Laboratoire de Génie Civil, des Géosciences et Sciences Géographiques, Institut National Polytechnique Félix Houphouët-Boigny, Yamoussoukro BP 1093, Côte d'Ivoire

[2]Département de Géologie, Université Abdou Moumouni, Faculté des Sciences et Techniques, Niamey BP 10662, Niger

[3]Centre d'Analyses et de Recherche, Société Nationale d'Opérations Pétrolières de Côte d'Ivoire, Abidjan BP V 194, Côte d'Ivoire

ABSTRACT: This study is a contribution to the petrographic and petrophysical characterization of the reservoir sandstones of Yogou Formation in the Termit Sedimentary Basin (Niger). It focuses on the impact of diagenetic processes on the petrophysical properties of Campanian sandstones. The pore types are generally intergranular, intragranular, and rare microcracks. The porosity varies from 0.3% to 25.3% and the permeability ranges from 0.1 mD to 470.3 mD. Diagenetic features that influenced the reservoir quality evolution include mechanical and chemical compaction, precipitation of carbonate cement, clay mineral cement, the formation of quartz overgrowths, and dissolution of feldspar grains. Compaction and cementation reduced significant volumes of primary porosity and permeability. On the other hand, feldspar dissolution and quartz corrosion contributed to an increase in the volume of primary porosity of the sandstones. The Yogou Formation reservoir was subjected to a high diagenetic overprint resulting in marked reservoir heterogeneity. This study also demonstrated the effect of diagenetic processes on the quality of hydrocarbon reservoirs and showed that good quality reservoirs are mainly concentrated in the 2545 m to 2565 m depth range of the study area.

KEYWORDS: Diagenesis, reservoir quality, porosity, permeability, Yogou Formation, Campanian sandstones.

1 INTRODUCTION

The Campanian age Yogou Formation is the new target for oil exploration and exploitation in the Termit Sedimentary Basin (Niger) [1]. Petroleum exploration in this Formation has shown the presence of source rocks [2], sandstone reservoirs, and caprock [3]. The discovery of hydrocarbon showings in the Campanian sandstones confirms the presence of oil in the Yogou Formation [4]. However, a study has shown the heterogeneity of these reservoirs [5], which may lead to difficulties in hydrocarbon exploitation [6]. Thus, no oil deposits are yet exploited in the Yogou Formation reservoirs.

Effective reservoir operation depends on several factors, including a better understanding of the impact of diagenetic weathering on reservoir quality (porosity and permeability) [7]. Diagenetic weathering controls the compaction between detrital grains, the dissolution of unstable minerals, and the degree of cementation that partially or fills the porous spaces of sandstones [8]. These diagenetic processes lead to the reduction and or generation of the porosity and permeability of the sandstones, which influences the quality of hydrocarbon reservoirs [9].

The objective of this work is to determine the main diagenetic processes that control the petrophysical properties including porosity and permeability of the Campanian sandstones of the Yogou Formation. This will help to distinguish good quality reservoir zones to advance petroleum exploration and development in the play area.

2 MATERIAL AND METHODS

The study area is located in the south-eastern part of Niger and belongs to the West and Central African rift system (WCARS) (Fig. 1) [10]. We collected samples from the sandstone Campanian age Yogou Formation, with a depth ranging from 2519.5 and 2610 m (Fig. 2, blue frame).

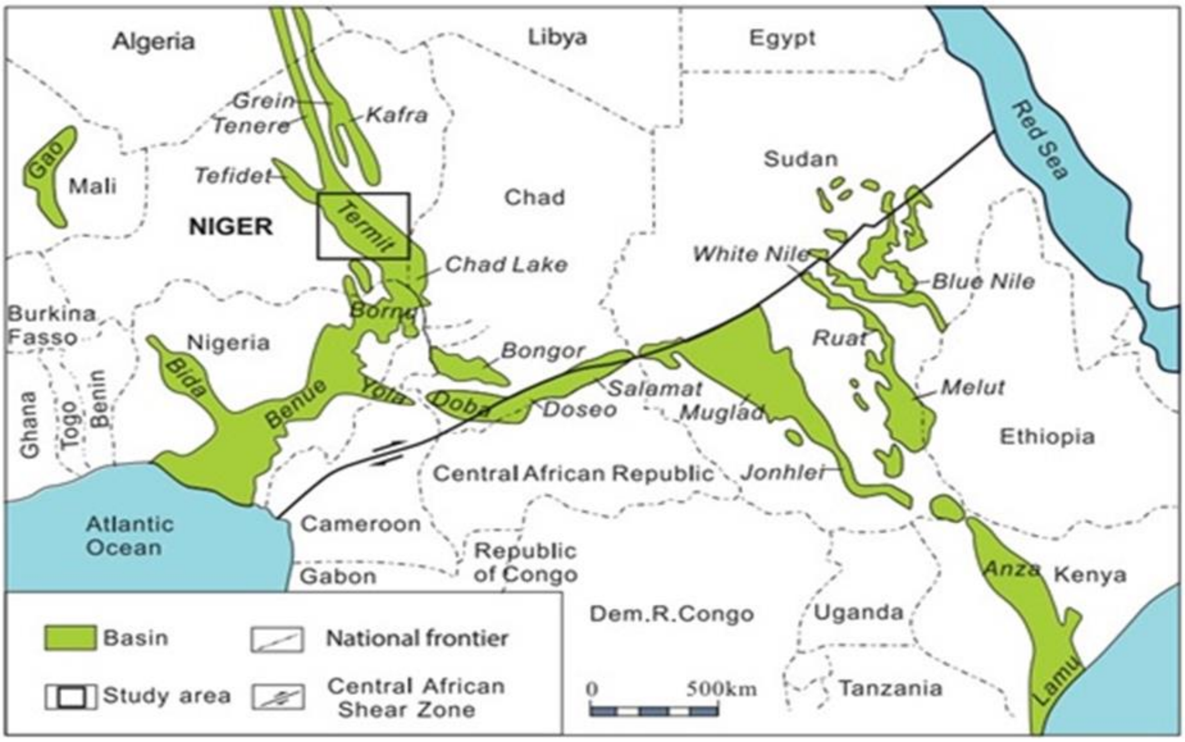

Fig. 1. Map showing the West and Central African Rift System (WCARS) with the location of the Termit Basin in Niger (after Genik, 1993)

The methods used in this work include thin section petrography, Pressure Decay Profile Permeameter (PDPK-400^{TM}), Scanning Electron Microscopy coupled with Energy Dispersion Spectrometry (SEM-EDS) and X-ray diffraction (XRD).

To identify the mineralogical composition, texture, and porosity of the sandstones on thin sections, the samples were impregnated with blue epoxy that colors the pores. The mineralogical quantification and porosity estimation of the sandstones were performed by counting 300 points per thin section. Permeability values were obtained by direct measurement on sandstone samples using a Pressure Decay Profile Permeameter (PDPK-400^{TM}).

The characterization of clays, texture, and diagenetic aspect of the sandstones were carried out using a FEG Supra 40 VP Zeiss Scanning Electron Microscope (SEM) equipped with an X-ray detector (OXFORD Instruments X-Max 20) connected to an EDS (Inca Dry Cool, Liquid Nitrogen Free) microanalyzer platform.

Clay minerals of a maximum of 2 µm were extracted from the sandstone samples by decarbonation and centrifugation. The identification of the clay minerals was carried out using a Bruker-type "D8 Advance" X-ray diffractometer (XRD) [11]. The semi-quantitative estimation of the main clay minerals (illite, chlorite, smectite, kaolinite, mixed or interlayered layers) was based on the work of [12].

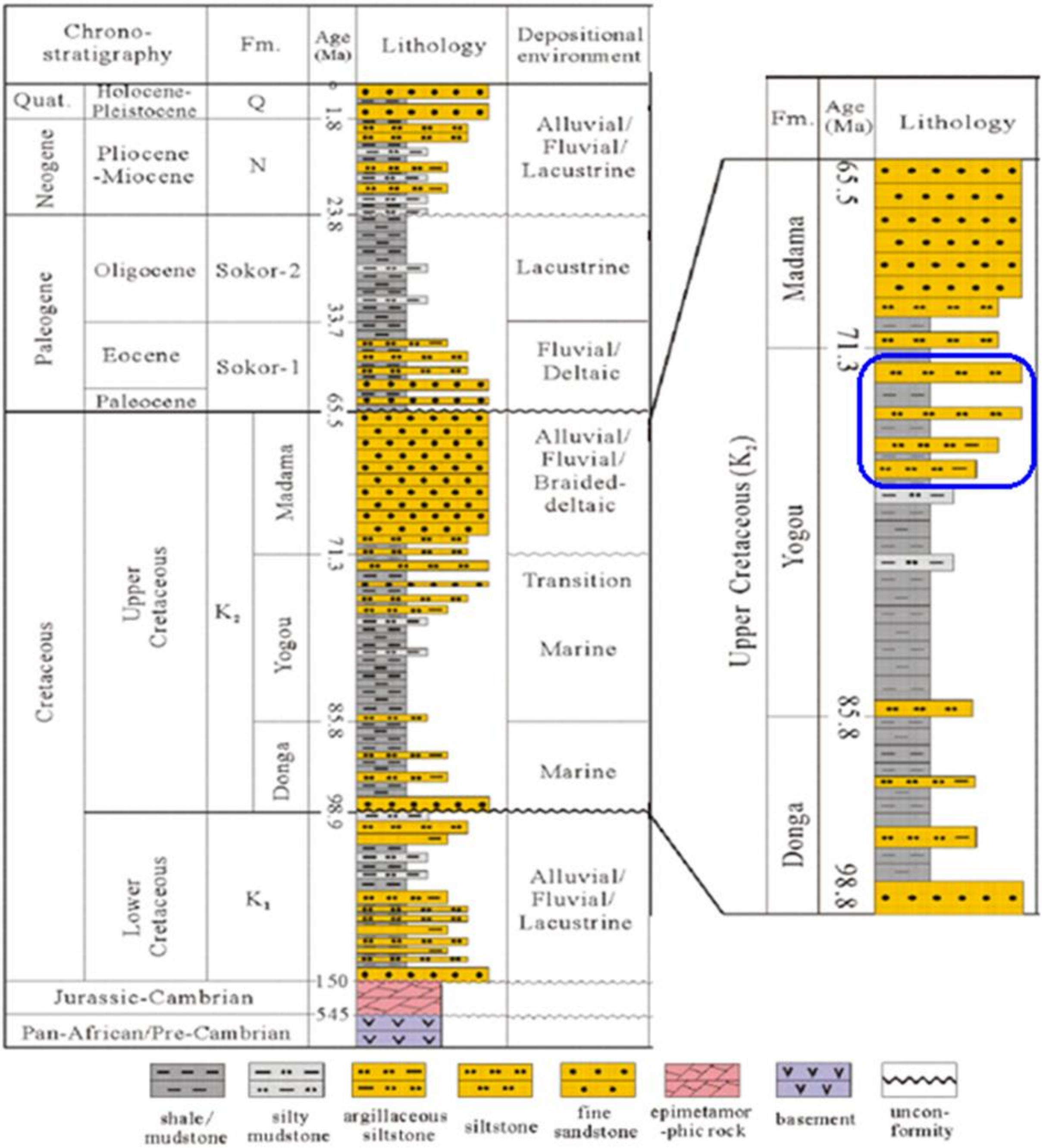

Fig. 2. Stratigraphic column of the Termit Basin (modified after Genik, 1993; Wan et al., 2014; Liu et al., 2015)

3 Results And Discussions

3.1 Petrographic Characterization Of Sandstones

3.1.1 Sandstone Composition And Texture

shows the results of the mineralogical composition and texture of the sandstones studied. The sandstone samples studied are composed of very fine to fine grained (Fig. 3A). Quartz is the predominant grains in the sandstones and generally occurs as monocrystalline and rare polycrystalline phase. The sand grains vary from subangular to subrounded and are moderately sorted (Fig. 3A, 3B). Feldspars are moderately abundant and include both plagioclase and microcline feldspars (Fig. 3F). The latter is characterized in thin sections by squared and polysynthetic macles for plagioclase [13]. Small quantities of lithic fragments are composed of detrital clay and mica. The detrital clay is sometimes in the form of illite flakes (Fig. 3G). The EDS spectrum of these flakes gives the following composition: Si (39.32%), Al (12.02%), Mg (0.84%), K (3.34%), Fe (18.97%) and Ti (1.96%) (Fig. 3H), typical of a detrital clay [14]. Micas are composed of biotite and muscovite (Fig. 3C, 3D, 3E). Biotite presents a brown to green pleochroism in the form of detrital flakes, while muscovite is in bright second-order colors under crossed polarities [15]. Aggregates of framboid and sub-cubic pyrite crystals (Fig. 3I) and rounded glauconitic pellets are observed (Fig. 3B).

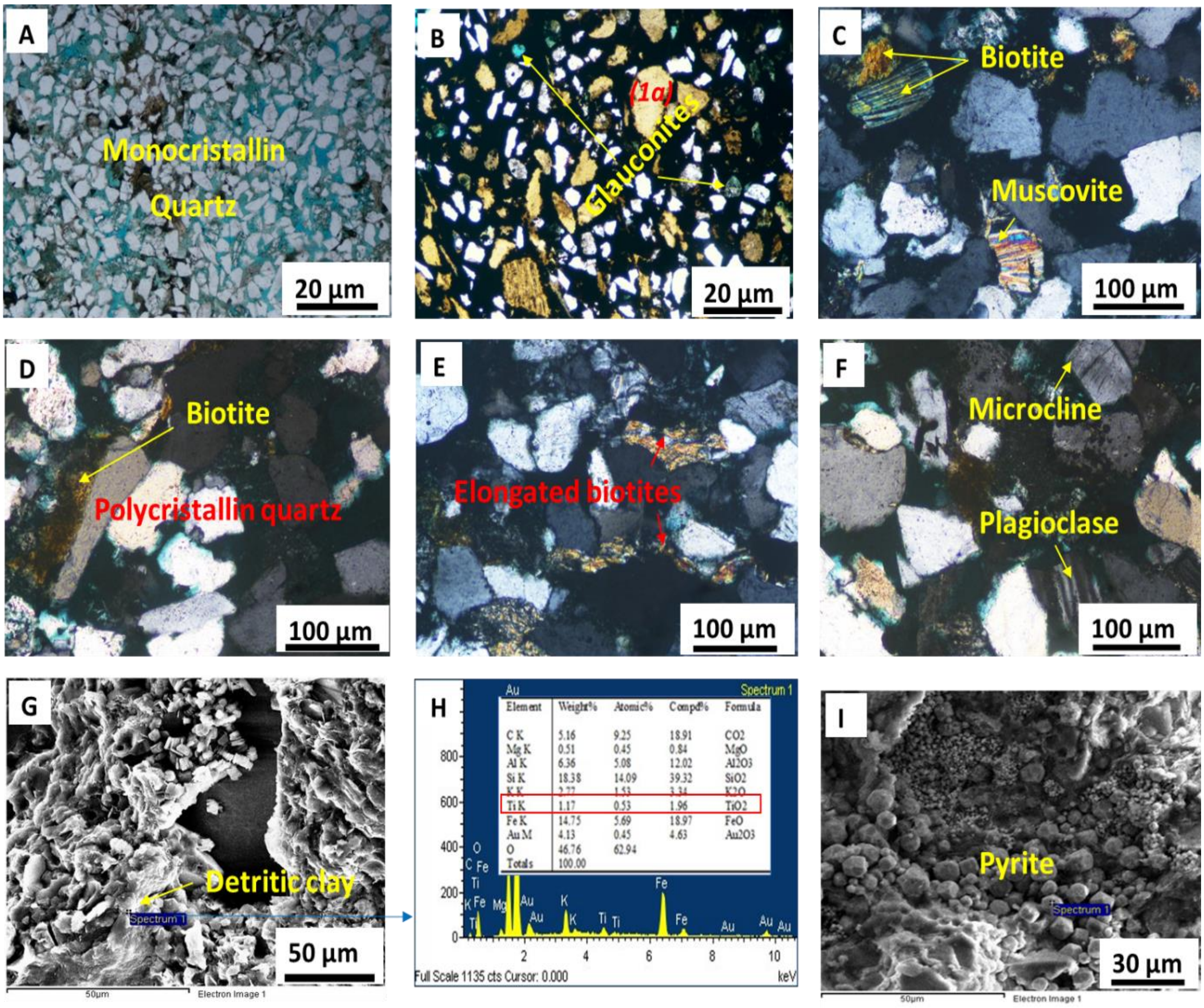

Fig. 3. Detrital clay spectrum (H), Scanning electron microscope images (G, I) and thin section photomicrographs in polarized light (A, B, C, D, E and F) of the Campanian sandstones samples

3.1.2 Porosity And Permeability

Porosity

Figures 4 and 5 present respectively the porosity results of points counting on all the thin sections analyzed and the pore types of the sandstones. In Figure 4, the porosity varies from 0.3 to 25.3% with an average of 13.4%. This porosity distribution diagram shows a decrease in porosity values as a function of depth as in [13].

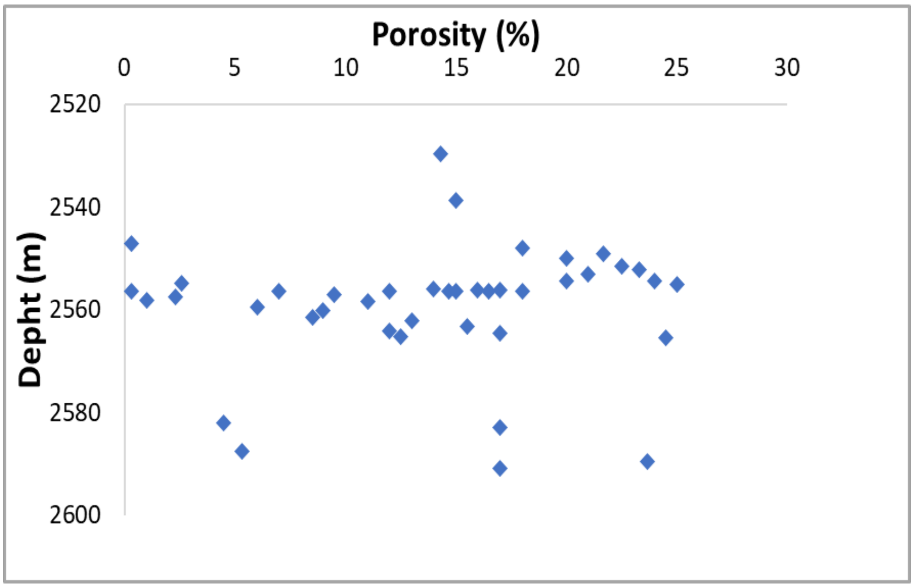

Fig. 4. Diagram of porosity variation versus depth in the Yogou Formation

In the depth range of this study, thin sections and SEM photomicrographs indicate three types of pores: intergranular, intragranular, and rare microcracks (Fig. 5A, 5B, 5C). The intergranular pores, which are more abundant, are affected by mechanical and chemical compaction (Fig. 7A, 7B, 7C), cementation of calcite (Fig. 5F), pyrite (Fig. 5E) and authigenic clay including kaolinite and chlorite (Fig. 5D, 5F). Intragranular pores are mainly associated with the dissolution of detrital feldspars and quartz corrosion (Fig. 5A, 5B, 5D). Microcracks are associated with the presence of organic-rich clay (Fig. 5C). Thus, compaction, the formation of calcite cement, pyrite cement, and clay minerals contributed to the decrease in porosity of the sandstones studied as in [16].

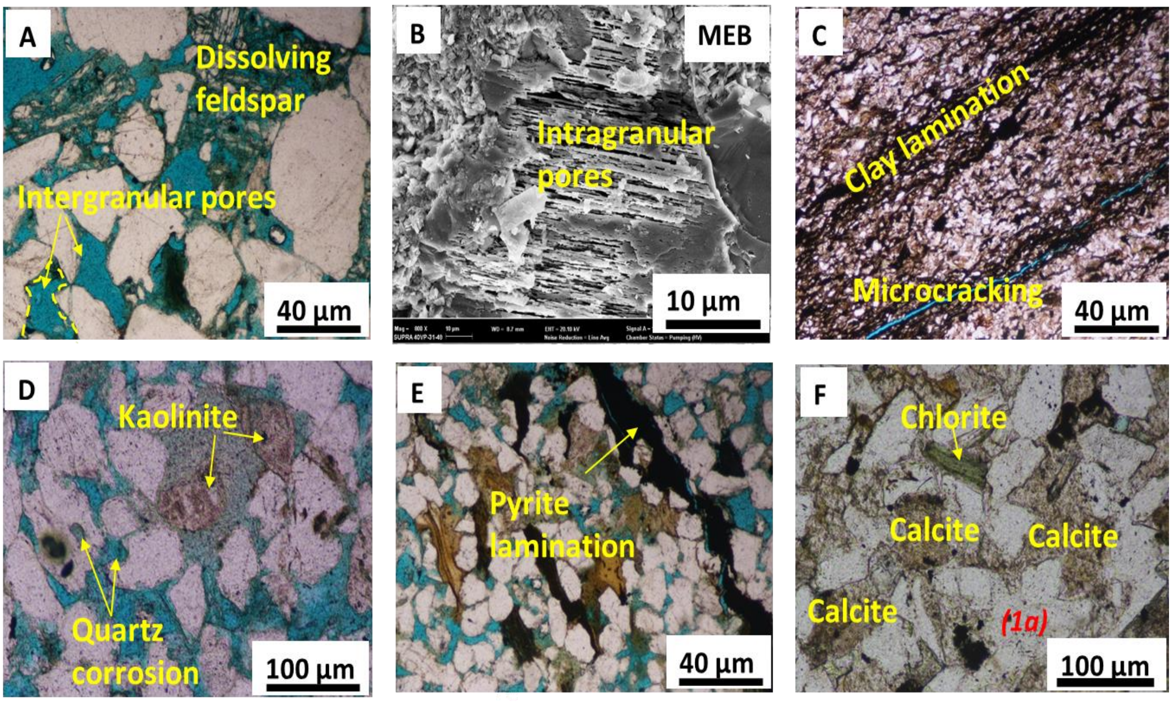

Fig. 5. Scanning electron microscope images (B) and thin section photomicrographs in polarized light (A, C, D, E and F) of the Campanian sandstones samples

PERMEABILITY

shows the permeability values measured on the sandstones studied. These values range from 0.1 to 470.3 mD with an average of 105.5 mD. This permeability distribution diagram shows a decrease in permeability values as a function of depth. The decrease in permeability with depth would be due to compaction and cementing, as for porosity. The decrease in porosity and permeability values in deep levels reflects a diagenetic control as in [6], [17].

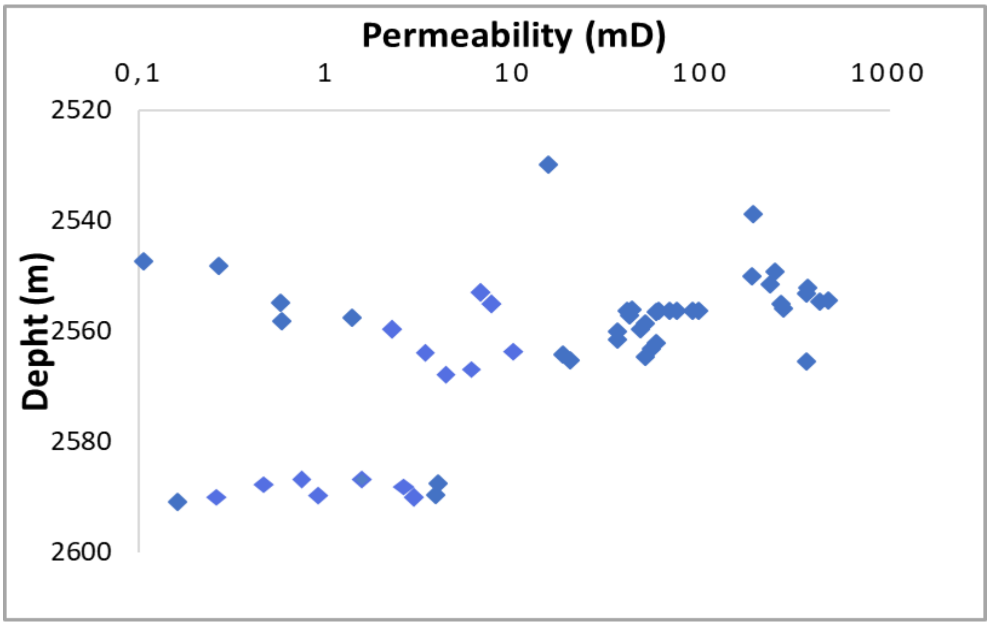

Fig. 6. Diagram of permeability variation versus depth in the Yogou Formation

3.1.3 DIAGENETIC PROCESSES

Figures 7, 8, 9, and 10 and present the results of the diagenesis of the studied sandstones. This diagenesis includes mechanical and chemical compaction, cementation, dissolution and recrystallization, and neoformation and replacement.

COMPACTION

The petrographic study of the studied sandstones has made it possible to distinguish several types of contacts between the grains: point, plane, concavo-convex, and sutured (Fig. 7A, 7B, 7C). Plane and concavo-convex contacts characterize mechanical compaction. The latter has reduced the volume of the intergranular porosity of the sandstones. Reference [18] showed the reduction of the intergranular porosity of the Lower Cretaceous Biyadh Reservoir sandstones of the Masila Basin (Yemen), due to changes in the contacts between the grains. During compaction, certain ductile minerals such as micas (biotite) are trapped in the quartz grains, filling the intergranular pores (Fig. 7B). The deformation of ductile minerals such as biotite also resulted in a loss of porosity during mechanical compaction as in [19], [20].

The chemical compaction is marked by the sutured contacts (Fig. 7A, 7B). Indeed, the physicochemical or sutured contacts result from the pressure-dissolution phenomenon at the contact between the quartz grains [21]. The pressure-dissolution phenomenon is at the origin of the formation of stylolites (Fig. 7B). The latter could also contribute to the formation of overgrowths around quartz grains, thus reducing the porosity and permeability of the sandstones (Fig. 7C) as in [22].

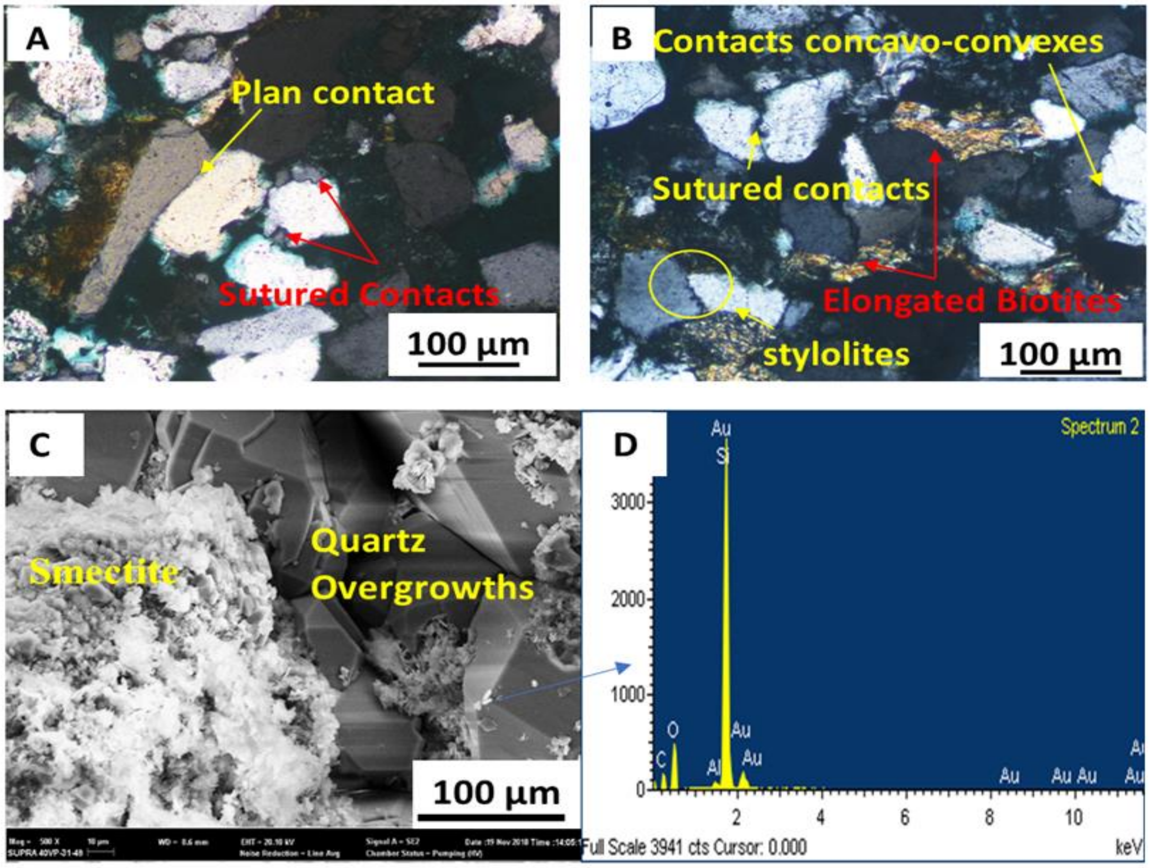

Fig. 7. Quartz overgrowths spectrum (D), Scanning electron microscope images (C) and thin section photomicrographs in polarized light (A, B) of the Campanian sandstones samples

CEMENTATION

In the sandstones studied, cementation is shown in thin sections by the presence of carbonate cement (Fig. 5F) and in SEM by that of iron oxides, clay minerals, and by overgrowths (secondary silica) around quartz grains (Fig. 8). Thus, the occlusion of intergranular and intragranular pores is observable in these Figures (5F and 8A, 8C, 8D, 8E, 8F, 8G, 8H) by the presence of calcite, siderite, pyrite, hematite, kaolinite, illite, chlorite and smectite cement.

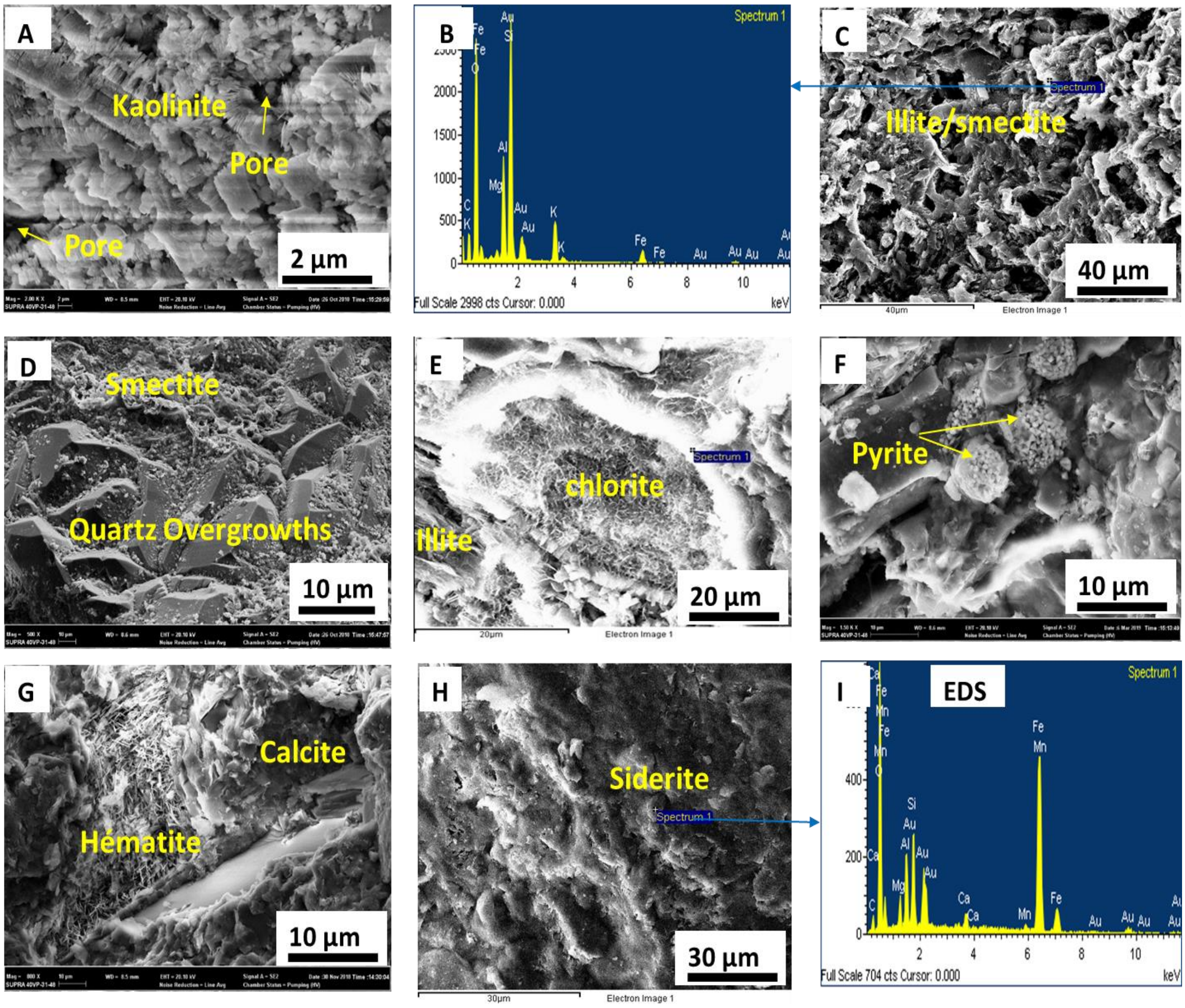

Fig. 8. Illite/smectite and siderite spectrums (B, I) and Scanning electron microscope images (A, C, D, E, F, G, H) of the Campanian sandstones samples

Kaolinite is the most abundant diagenetic clay mineral with an average of 71.5% (Table 1). It occurs in SEM as stacked, booklet-type, and pseudo-hexagonal aggregates (Fig. 8A). Kaolinite fills the intragranular pores and replaces feldspar grains (Fig. 5D, 8A) as in [23]. Illite (Fig. 8E) is the secondary clay mineral with an average of 12.1% (Table 1). There is an increase in its proportion with depth, which indicates the proliferation of illite during burial. The mixed illite/smectite layers have an average of 3.7% in the analyzed samples (Table 1). They are distinguished from illite by their SEM mat texture, covering grain surfaces and pore spaces (Fig. 8B, 8C) as in [14]. Smectite is present but in a small proportion (1.2%). Most of the smectite probably transformed into illite through the mixed illite/smectite layers during progressive burial as in [24]. Smectite is identified by XRD, EDS, and SEM through its expansion property (Fig. 7C, 8D). Smectite coatings are also noted on quartz overgrowths (Fig. 7C, 8D). The smectite coatings on the quartz overgrowths were trapped during pressure-dissolution [25]. Authigenic chlorite (1.2%) is present in the SEM as honeycomb (Fig. 8E) as in [24]. Chlorite is generally formed during the transformation of smectite into illite, using the iron and magnesium from the smectite [26]. Glauconite is identified by XRD with an average of 10.3% (Table 1). Glauconite is presented as a thin section with light green rounded peloids (Fig. 3B) as in [27].

Tableau 1. XRD results showing the percentages of clay minerals identified in Campanian sandstones

Samples	Depht (m)	K (%)	I (%)	I/Sm (%)	Sm (%)	Ch (%)	G (%)
A-1	2525,0	87,1	5,7	2,2	1,6	1,6	1,8
A-2	2534,5	61,8	6,0	5,6	8,0	4,9	13,7
A-3	2545,0	73,9	9,6	4,0	0,0	0,0	12,5
A-4	2551,5	73,8	9,1	1,9	0,0	0,0	15,2
A-5	2561,5	66,7	21,4	6,5	0,0	0,0	5,4
A-6	2570,0	60,0	16,4	4,4	0,0	2,7	16,5
A-7	2582,0	73,5	17,7	2,0	0,0	0,0	6,8
A-8	2590,5	76,2	11,0	2,6	0,0	0,0	10,2
Average		71,5	12,1	3,7	1,2	1,2	10,3

Carbonate cement is represented by calcite and siderite. Siderite (Fig. 8H) is characterized at SEM-EDS by a high peak in Ca and Mn (Fig. 8I) as in [14]. Calcite is characterized by its brown color in thin section (Fig. 5F). Quartz overgrowths are marked by secondary silica around the detrital grains (Fig. 7C, 8D). Iron oxides are dominated by hematite (Fig. 8G). In most of the samples analyzed, pyrite (Fig. 8F) forms cement and/or opaque thin sections, filling pore spaces, and microcracks (Fig. 5E). This indicates that pyrite has a negative impact on the porosity and permeability of sandstones as in [28].

The petrographic analysis carried out in this work highlighted the reduction of porosity and permeability by calcite, siderite, pyrite, kaolinite, illite, chlorite, and mixed illite/smectite layers as in [11], [13], [21], [25].

Dissolution And Recrystallization

The dissolution of the feldspar grains resulted in the creation of intragranular pores (Fig. 9B). This dissolution is sometimes followed by kaolinite precipitation (Fig. 9A). Indeed, the neoformed clay mineral (kaolinite) blocked some secondary pores. Reference [29] showed the replacement of feldspar by kaolinite in the tight bituminous sandstones of Chang 8 of the Upper Triassic of the Ordos Basin (China), leading to the heterogeneity of the reservoir.

In some cases, the dissolution of feldspars created intragranular pores (Fig. 9B), thus contributing to increase the porosity. These intragranular pores were isolated and therefore not connected. This configuration does not promote permeability. For this reason, the impact of feldspar dissolution on reservoir quality was considered low.

The thin section petrographic study also revealed the phenomenon of dissolution by corrosion of quartz grains (Fig. 5D). This phenomenon characterizes a pronounced alteration during the diagenesis [13]. The dissolution of feldspars and or quartz contributed to the formation of silica which recrystallized as overgrowths around the feldspar or quartz grains (Fig. 9A). These quartz overgrowths obstructed large primary pores of the studied sandstones (Fig. 7C, 8D) as in [30].

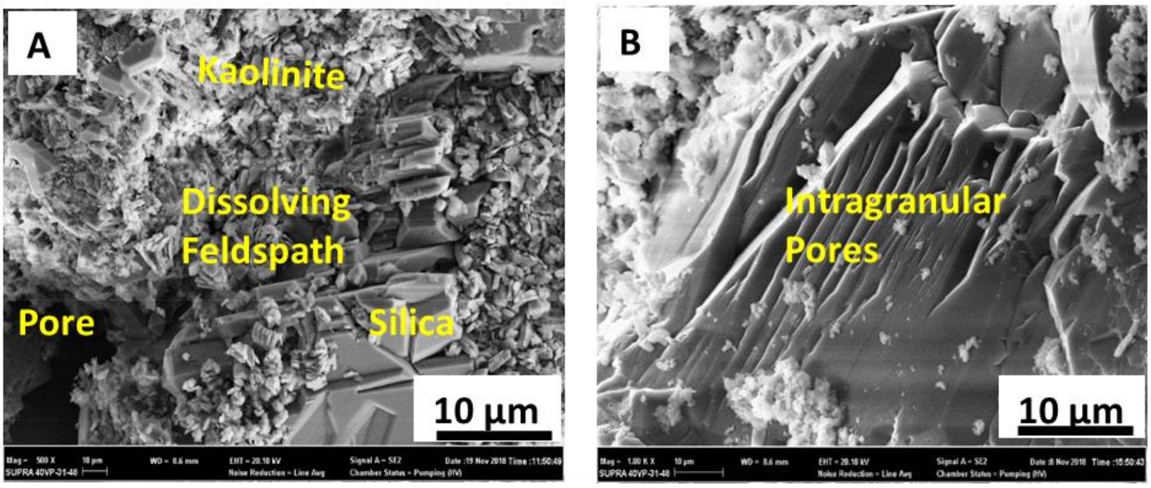

Fig. 9. Scanning electron microscope images (A, B) of the Campanian sandstones samples

NEOFORMATION AND REPLACEMENT

The main neoformation observed in the sandstones studied is the disappearance of feldspar and its replacement by kaolinite (Fig. 10A). This diagenetic process is followed by the replacement of thin crystals of kaolinite by illite (Fig. 10B) as in [13]. This shows that the studied sandstones have reached the late diagenesis stage. Muscovite filaments were also observed, indicating the partial or total replacement of micas by siderite (Fig. 10C) as in [25]. Precipitation of siderite from mica has also been demonstrated in the micaceous sandstones of Statfjord Satellite in the North Sea [31].

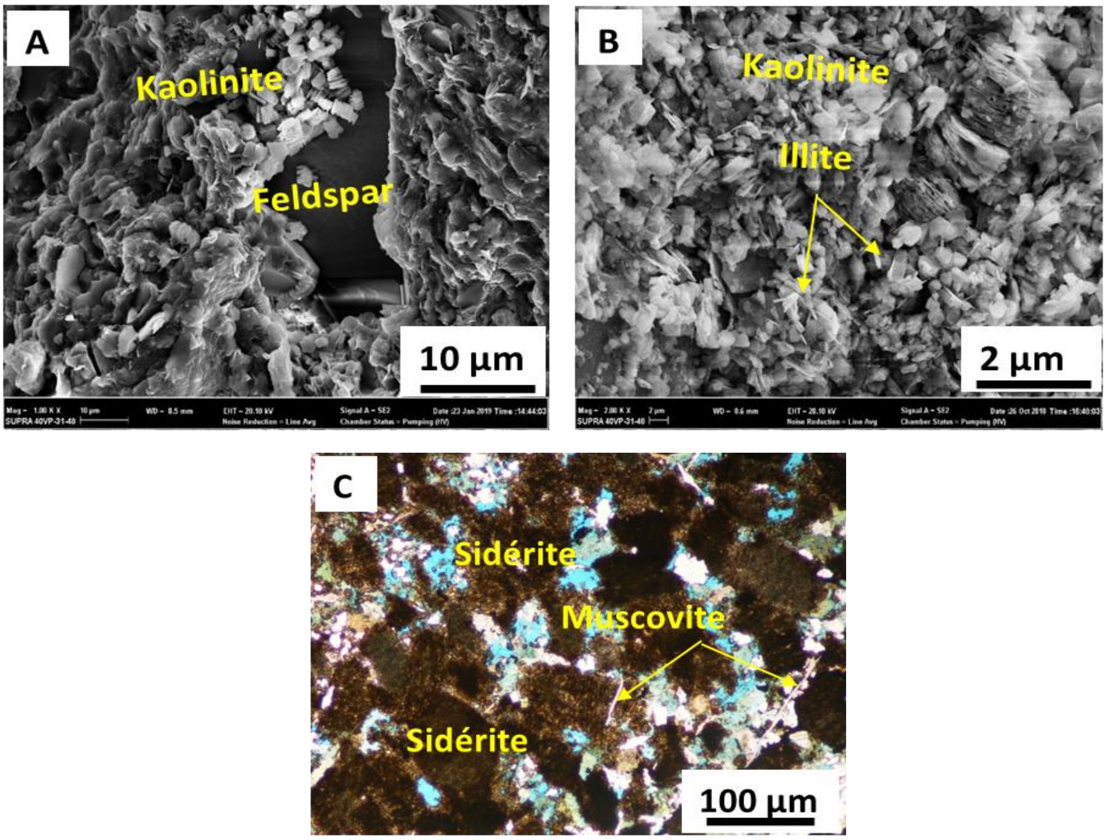

Fig. 10. Scanning electron microscope images (A, B) and thin section photomicrographs in polarized light (C) of the Campanian sandstones samples

4 CONCLUSION

The purpose of this study was to determine the main diagenetic processes that control the petrophysical properties including porosity and permeability of the Yogou Formation reservoirs. The methods used showed that these reservoirs have a wide range of porosity (0.3%-25.3%) and permeability (0.1 mD-470.3 mD), indicating diagenetic control. The main diagenetic processes influencing these porosity and permeability values include mechanical and chemical compaction, cementing of calcite, siderite, pyrite, kaolinite, illite, chlorite, smectite, glauconite, mixed illite/smectite layers, the formation of quartz overgrowths and dissolution of feldspar. In the depth range of the present study (2519.5 and 2610 m), the precipitation of carbonate cement, iron oxides, and the neoformation of dominant clays including kaolinite, illite, and glauconite significantly reduced the porosity and permeability of the sandstones. On the other hand, the dissolution of feldspars and quartz corrosion contributed to an increase in the volume of primary porosity of the sandstones. The study also showed that diagenetic processes have more impact in reservoirs located above 2570 m. These reservoirs have the lowest permeability values (0.1 to 3.9 mD), which may make hydrocarbon development operations difficult in this area. However, in the 2525 to 2565 m depth range, sandstones have the highest porosity (25.3%) and permeability (470.3 mD) values, indicating the presence of better quality reservoirs. This study also showed that the heterogeneity of the reservoirs of the Yogou Formation can be linked to the presence of unstable detrital grains such as feldspars, micas, and lithic fragments.

ACKNOWLEDGMENTS

This work was supported by Fund for Scientific Research and Technological Innovation of Niger. Thanks to the Secretary-General of the Ministry of Petroleum of Niger and his colleagues of the Hydrocarbons Direction, who allowed us to take samples at the CDP (Centre de Documentation et Archives Pétroliers du Niger).

REFERENCES

[1] Y. Shengqiang, M. Fengjun, Z. F. Zhang, G. L. Jiguo, L. Mingsheng, and X. Cheng, “Analysis and exploration strategy for Upper Cretaceous reservoirs in the Termit Basin, Niger,” Science Earth Science Frontiers, P. 18, 2016.

[2] H. Lai, M. Lia, J. Liu, F. Mao, H. Xiao, W. Heb, and L. Yang “Organic geochemical characteristics and depositional models of Upper Cretaceous marine source rocks in the Termit Basin, Niger,” Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 495, p. 17, 2018.

[3] Z. Ning, G. Xia, H. Jiangqin, C. Zhongmin, and Z. Guangya, “Sedimentary Characteristics and Lithological Trap Identification of Distant Braided Delta Deposits: A Case on Upper Cretaceous Yogou Formation of Termit Basin, Niger,” Proceedings of the Third International Conference on the Progress of Energy and Environment Research (CAEER 2018), p. 10, 2018.

[4] Arthur Satterley, Competent persons report: Agadem Exploration License R1/R2, Niger for Savannah Petroleum PLC and Strand Hanson Limited. Robertson (UK) Limited, No: BP443, 2014.

[5] J. Fu, R. Kang, Z. Jiang, C. Zhou, and K. Liu, “Microcharaters of mesozoic-cenozoic reservoir in Agadem block of Niger,” Journal of Henan Polytechnic University (Natural Science), no 3, p. 9, 2013.

[6] P. Zhang, J. Zhang, and J. Wang, “Diagenesis and reservoir quality in continental fault-block reservoirs: Evidence from the Second Member of Shahejie Formation, Dongying Sag, Eastern China, ” International Journal of Innovation and Applied Studies, vol. 5, no 3, p. 200-205, mars 2014.

[7] M. A. Islam, “Diagenesis and reservoir quality of Bhuban sandstones (Neogene), Titas gas field, Bengal Basin, Bangladesh,” Journal of Asian Earth Sciences, vol. 35, no 1, p. 89–100, 2009.

[8] R. M. Slatt, Stratigraphic reservoir characterization for petroleum geologists, geophysicists, and engineers. Elsevier, 2006.

[9] M. K. Salah, M. M. El Ghandour, and A. M. T. Abdel-Hameed, “Effect of diagenesis on the petrophysical properties of the Miocene rocks at the Qattara Depression, north Western Desert, Egypt,” Arabian Journal of Geosciences, vol. 9, no 5, p. 329, 2016.

[10] G. J. Genik, “Petroleum geology of Cretaceous-Tertiary rift basins in Niger, Chad, and Central African Republic,” AAPG Bulletin, vol. 77, no 8, p. 1405–1434, 1993.

[11] G. Lorenzi, D. Bossiroy, R. Dreesen, and L. Issep, The use of Clay minerals in stratigraphic correlations of carboniferous coal deposits. Report final, 1992.

[12] P. E. Biscaye, “Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans,” Geological Society of America Bulletin, vol. 76, no 7, p. 803–832, 1965.

[13] I. Fea, B. Fofana, J. P. N. Yao, H. Y. Kplohi, E. T. Goua, B. Z. Digbehi, and K. M. Bamba, "Diagenetic control on the petrophysical properties of Albian Cenomanian sandstones in the Ivorian basin, west Africa," International Journal of Innovation and Scientific Research, vol. 39, no 2, p. 120-138, nov. 2018.

[14] J. E. Welton, SEM petrology atlas: Chevron Oil Field Research Company. The American Association of Petroleum Geologists Tulsa, Oklahoma 74101, U.S.A, 1984.

[15] Y. M. Makeen, W. H. Abdullah, H. A. Ayinla, M. H. Hakimi, and S. G. Sia, "Sedimentology, diagenesis and reservoir quality of the upper Abu Gabra Formation sandstones in the Fula Sub-basin, Muglad Basin, Sudan," Marine and Petroleum Geology, vol. 77, p. 1227–1242, 2016.

[16] C. Liu, L. Sun, J. Lu, Y. Sun, Y. Xu, M. Lu, and J. Li, "Characteristics of the newly found oil-bearing sandstone in the Denglouku formation of the northern Songliao Basin, China," Journal of Petroleum Science and Engineering, p. 106947, 2020.

[17] K. Bjørlykke, "Relationships between depositional environments, burial history and rock properties: Some principal aspects of diagenetic process in sedimentary basins," Sedimentary Geology, vol. 301, p. 1–14, 2014.

[18] M. H. Hakimi, M. R. Shalaby, and W. H. Abdullah, "Diagenetic characteristics and reservoir quality of the Lower Cretaceous Biyadh sandstones at Kharir oilfield in the western central Masila Basin, Yemen," Journal of Asian Earth Sciences, vol. 51, p. 109–120, 2012.

[19] A. Makowitz and K. L. Milliken, "Quantification of Brittle Deformation in Burial Compaction, Frio and Mount Simon Formation Sandstones," Journal of Sedimentary Research, vol. 73, no 6, p. 1007-1021, nov. 2003.

[20] V. C. Hover, D. R. Peacor, and L. M. Walter, Relationship Between: Organic Matter And authigenic Illite Smectite in Devonian Black Shales, Michigan and Illinois Basins, USA, 1996.

[21] R. H. Worden and S. Morad, "Quartz cementation in oil field sandstones: a review of the key controversies," in: Worden, R.H., and Morad, S. (eds), Quartz Cementation in Sandstones. International Association of Sedimentologists, Special Publication, v. 29, p.1-20, 2000.

[22] K. Xi, Y. Cao, J. Jahren, R. Zhu, K. Bjørlykke, X. Zhang, L. Cai, and H. Hellevang, "Quartz cement and its origin in tight sandstone reservoirs of the Cretaceous Quantou formation in the southern Songliao basin, China, " Marine and Petroleum Geology, vol. 66, p. 748-763, sept. 2015.

[23] R. H. Worden and S. Morad, "Clay minerals in sandstones: a review of the detrital and diagenetic sources and evolution during burial in Clay Mineral Cements in Sandstones," International Association of Sedimentologists, vol. 34, Special Publication, p. 3–41, 2003.

[24] H. C. G. Paredes, O. Catuneanu, and U. H. Romano, "Controls on the quality of Miocene reservoirs, southern Gulf of Mexico," Journal of South American Earth Sciences, vol. 81, p. 45–65, 2018.

[25] F. El-Khatri, M. A. K. El-Ghali, H. Mansurbeg, S. Morad, N. Ogle, and R. M. Kalin, "Diagenetic alterations and reservoir quality evolution of lower cretaceous fluvial sandstones: Nubian formation, Sirt basin, north-central Libya, " Journal of Petroleum Geology, vol. 38, no 2, p. 217–239, 2015.

[26] H. Chamley, Clay mineralogy. 1989.

[27] P. Assale, S. Monde, et K. Aka, "Caractérisation lithostratigraphique et petro sédimentologique des formations tertiaire-quaternaires de la region de Bingerville (Côte d'Ivoire)," http://www.afriquescience.info, 2012.

[28] A. Abu Mostafa, A. M. Abu Khadrah, and A. A. Refaat, "Impact of diagenesis on reservoir quality evolution of the late Cenomanian Abu Roash "G" Member in the Sitra Field, North Western Desert, Egypt," Marine and Petroleum Geology, vol. 95, p. 255-264, Août 2018.

[29] M. Wang, H. Tang, F. Zhao, S. Liu, Y. Yang, L. Zhang, J. Liao, and H. Lu, "Controlling factor analysis and prediction of the quality of tight sandstone reservoirs: A case study of the He8 Member in the eastern Sulige Gas Field, Ordos Basin, China," Journal of Natural Gas Science and Engineering, vol. 46, p. 680-698, oct. 2017.

[30] J. E. Cook, L. B. Goodwin, and D. F. Boutt, "Systematic diagenetic changes in the grain-scale morphology and permeability of a quartz cemented quartz arenite," AAPG bulletin, vol. 95, no 6, p. 1067–1088, 2011.

[31] S. N. Ehrenberg, "Influence of depositional sand quality and diagenesis on porosity and permeability; examples from Brent Group reservoirs, northern North Sea," Journal of Sedimentary research, vol. 67, no 1, p. 197–211, 1997.