Scientific Research Publishing

Open Journal of Geology, 2023, 13, 1139-1150
https://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

Geochemistry of Cretaceous Sea Rocks from the LEO-3X Well in the Eastern Abidjan Margin, Côte d'Ivoire Offshore Basin

Chia Marie Reine Kokoa[1], Lassey Lou Soholy Ange Claverie[2], Ahouré Nguessan Donald[3], Allialy Marc Ephrem[1], Coulibaly Sougo Aoua[1], Affian Kouadio[1]

[1]UFR/STRM, Felix Houphouet-Boigny University of Abidjan, Abidjan, Côte d'Ivoire
[2]UFR/ARHAI, San Pedro University of Côte d'Ivoire, San Pedro, Côte d'Ivoire
[3]Sciences and Techniques, Alassane Ouattara University of Bouaké, Bouaké, Côte d'Ivoire
Email: reinek4720@gmail.com

How to cite this paper: Kokoa, C.M.R., Claverie, L.L.S.A., Donald, A.N., Ephrem, A.M., Aoua, C.S. and Kouadio, A. (2023) Geochemistry of Cretaceous Sea Rocks from the LEO-3X Well in the Eastern Abidjan Margin, Côte d'Ivoire Offshore Basin. *Open Journal of Geology*, **13**, 1139-1150.
https://doi.org/10.4236/ojg.2023.1310047

Received: August 11, 2023
Accepted: October 27, 2023
Published: October 30, 2023

Abstract

In this study, we apply geochemical and statistical analyses to evaluate the source rocks and kerogen type of Cretaceous sediments from the Cote d'Ivoire sedimentary basin. The geochemical analysis includes pyrolysis data such as total organic carbon (TOC%), generation source potential (S2) and hydrogen index (HI). The results of the cluster analysis separated the source rocks in the study area into two main groups. 1) Source rocks characterized by HI > 300 (mg/g), TOC from 1.76% to 3.19% by weight, and S2 from 6.55 to 14.46 (mg/g), indicating good to excellent source rocks with type II kerogen and are capable of generating oil. 2) Source rocks characterized by HI between 200 and 300 (mg/g), TOC from 1.6 to 2.02 wt%, and S2 from 3.45 to 5.36 (mg/g) indicating medium to good source rocks with type II-III kerogen and capable of generating a mixture of oil and gas.

Keywords

Bedrock, Kerogen, Offshore Basin, Cretaceous, Côte d'Ivoire

1. Introduction

Petroleum geochemistry is used as a fundamental science to understanding the properties of source rocks, productive zones and more efficient exploration, oilfield development and sustainable production. The term source rock refers to a fine-grained sedimentary rock rich in organic matter that can produce hydrocarbons through thermal maturation [1]. In Côte d'Ivoire, the Cretaceous, a period of interest for oil companies, has been the subject of numerous studies in-

cluding PETROCI and its partners [2] [3] [4] [5] [6]. Thus, these studies revealed different lithologies between the Albian and the Maastrichtian. However, in these earlier studies, work on the potential source rocks of the Ivorian Basin was little addressed. The few results obtained showed that source rocks exist in all the basin's series. Some stratigraphic levels have better petroliferous potential than others, and the hydrocarbon generated is either gas, oil, or a mixture of oil and gas [3] [7] [8]. The aim of the present work is to provide more knowledge about the quality of source rocks, namely their organic matter (kerogen) content, and the type of kerogen it contains. After a brief presentation of the study area, the analytical methods adopted are outlined, then the results are interpreted and discussed.

2. Material and Method

2.1. Presentation of the Study Zone

In the context of this work, the well-studied is located in the Abidjan margin (Figure 1). It is the LEO-3X well, with geographic coordinates 4˚05'58.84"N and 3˚43'06.52"W.

2.2. Data Analysis

Ninety-six (96) cuttings from the HIPPO-1X well were used for this geochemical and sedimentological study.

After the lithological description, twenty grams (20 g) of sediment from each sample were soaked in soapy water for 45 minutes. Before air-drying at room temperature and homogenization using a porcelain pestle and mortar, the sediments were treated with water on a column of two sieves (100 and 63 µm). The prepared samples were subjected to Rock-Eval 6 analysis for the determination of four (4) geochemical parameters:

- Maximum pyrolysis temperature (Tmax), which quantifies the thermal maturation of organic matter;
- petroleum potential (S2), which indicates the quantity of "potential" or residual

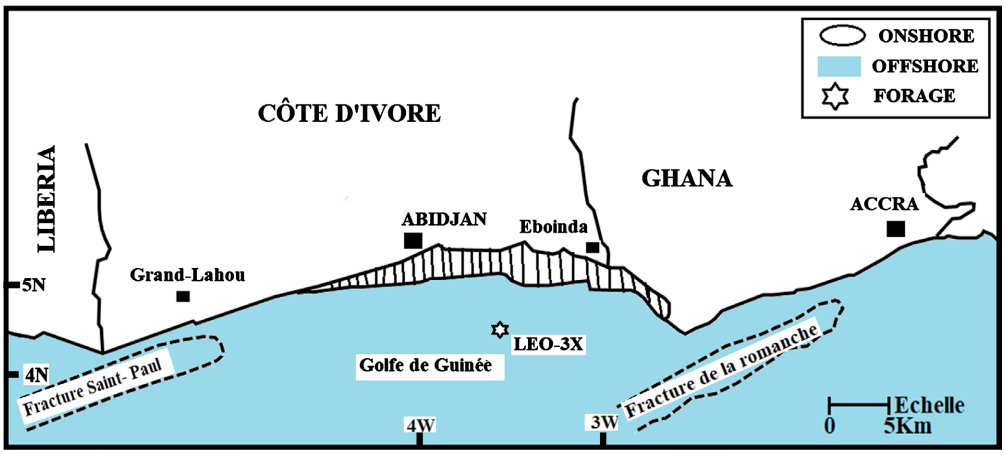


Figure 1. Location of LEO-3X study well.

hydrocarbons that could be produced if burial and maturation continue;

- Total Organic Carbon (TOC), is used to assess the petroleum potential of organic matter (OM);
- Hydrogen Index (HI): the proportion of hydrocarbon effluents emitted during pyrolysis in relation to TOC. It is used to assess the type and origin of organic matter present in sedimentary rocks.

The geochemical data were interpreted in parallel with the S2/TOC and HI/TOC diagrams. They are associated with stratigraphic stages to better assess the presence or absence of bedrock and the type of kerogen it contains.

3. Results

3.1. Deposit Environment

The formations studied range from 2498 m to 1372 m and have been subdivided into three lithological intervals, each comprising two units. From base to summit, we distinguish three intervals named 1, 2 and 3.

Interval 1

This interval, with a height of 136 m, lies between elevations 2498 m and 2362 m. It is characterized mainly by marl, limestone and argillite. Two lithological units can be distinguished in this interval (Figure 2).

Unit 1 (2498 m - 2426 m) is predominantly calcareous with argillite intercalations. The limestone is light brown, sometimes light gray, hard with a microcrystalline texture, clayey, with oligosteginides. The argillite is dark gray, firm, massive, slightly calcareous, micromicaceous, with traces of pyrite and carbonaceous micro-debris.

Unit 2 (2426 m - 2362 m) is characterized by alternating marl and argillite, with marl predominating. The marl is brownish-grey and subfissile. The argillite is dark gray, firm to crumbly, massive, sometimes subfissile, slightly calcareous, micromicaceous. Carbonaceous debris can be observed in this interval, with the percentage gradually decreasing from base to top. Glauconite is virtually absent and pyrite is present. This suggests deposition in a reductive environment with

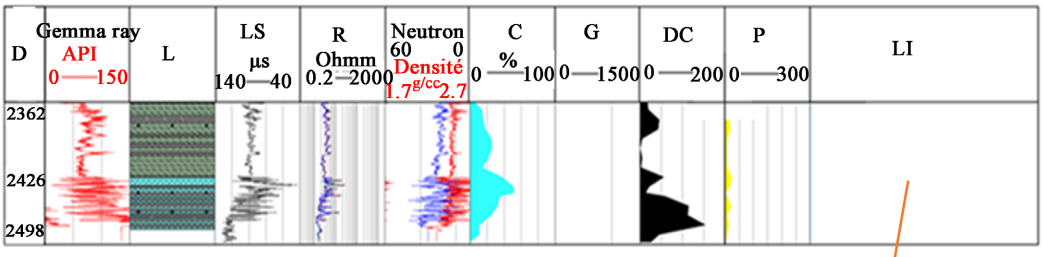


Figure 2. Litho-diagraphic log of sediment deposits in interval 2 of the LEO-3X well.

continental influences. The sediments contain high levels of calcium carbonate, ranging from 10% to 50%. This is explained by the lithology, which consists of marl and limestone rich in foraminifera.

Interval 2

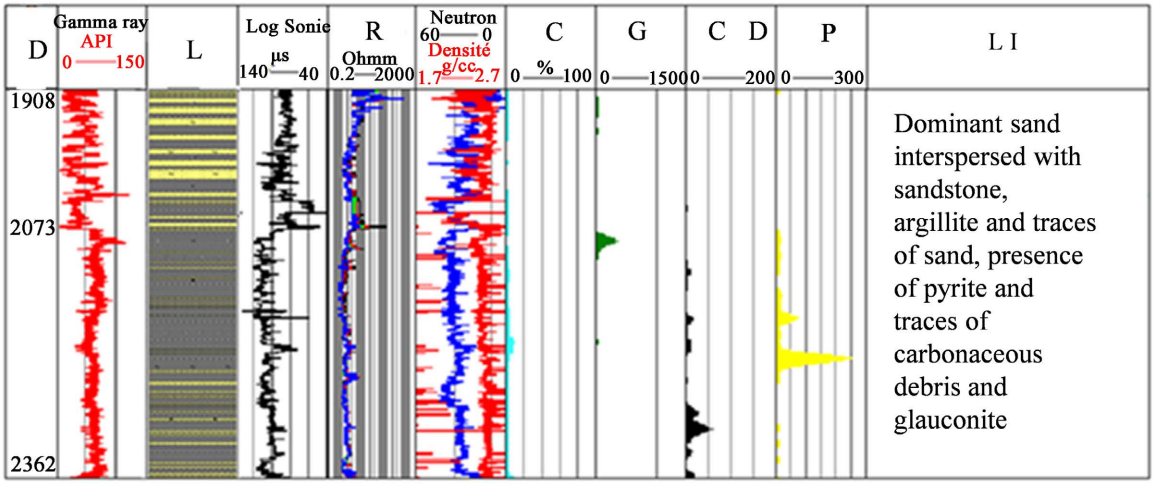
This interval (2362 m - 1908 m) is characterized by alternating sand, sandstone, argillite and kaolinite. It is subdivided into two units (Figure 3).

Unit 1 (2362 m - 2073 m), 289 m high, is characterized by a predominance of argillite and fine sand. The argillite is brownish-gray to dark gray, firm, friable, massive, sometimes subfissile, slightly calcareous, micromicaceous, with traces of pyrite and carbonaceous micro-debris. The sand, mainly between coasts 2332 m and 2362 m, is translucent, fine to coarse, subrounded and moderately sorted.

Unit 2 (2073 m - 1908 m) is characterized by a series of sand, sandstone, kaolinite and argillite of varying proportions. The sand is translucent, sometimes transparent, fine to coarse, subangular to rounded, and poorly sorted. Sandstones are light gray, friable to firm, very fine to fine-grained, subrounded to rounded, moderately to well sorted, with siliceous cement and limestone in places, micromicaceous. Kaolonite is white, friable, slightly sandy and micro micaceous. Clayite is dark gray, firm, massive to subfissile, non-calcareous, and silty, with calcareous fossil debris. Pyrite is present, glauconite is abundant in places and carbonaceous debris is virtually absent, suggesting an anoxic marine environment with little continental influence. The calcium carbonate content of the sediments is relatively low, peaking at around 15% at elevation 2207 m. This is due to the presence of alternating thick layers of dark-gray, non-calcareous to slightly calcareous argillite and thin banks of calcareous-cemented sandstone, with few foraminifera.

Interval 3

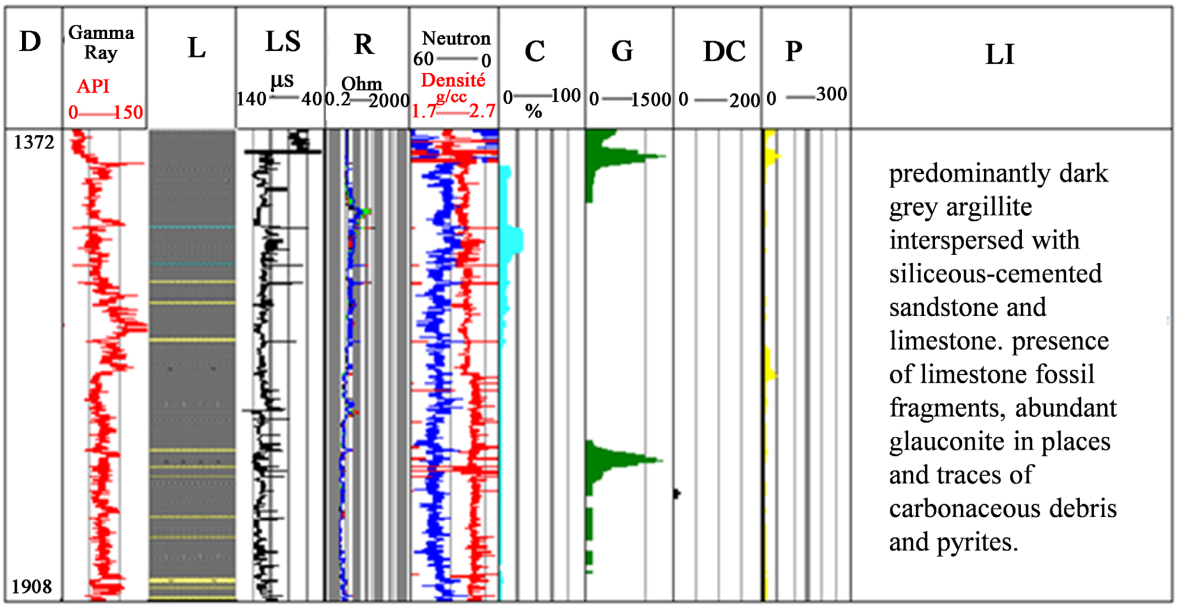
This interval extends from 1908 m to 1372 m. It is clay-dominated and subdivided



D : Depth ; L : Lithology ; LS : Log sonic ; R : resistivity ;
C : calcimetry ; G : Glauconite ; DC : carbonaceous debris
P : pyrite ; L I : litholigic interval

Figure 3. Litho-diagraphic log of sediment deposits in interval 3 of the LEO-3X well.

into two units (Figure 25). Unit 1 (1908 m - 1631 m), 277 m high, is characterized by argillite and traces of sandstone. The argillite is dark gray to brownish gray, firm, massive, subfissile, very slightly calcareous, very glauconitic and containing fragments of calcareous fossils. Sandstones are light gray, hard, very fine-grained, well sorted and siliceous-cemented. Unit 2 (1631 m - 1372 m) is characterized by a dominant argillite series and fine limestone beds. The argillite is dark gray to brownish gray, firm, massive, subfissile, very slightly calcareous, glauconitic and containing calcareous fossil debris. Limestone is light brown, hard, microcrystalline in texture and slightly clayey. Pyrite is present in small quantities. Glauconia is also abundant in places, and carbonaceous debris is virtually absent, suggesting an anoxic marine environment with little continental influence. The calcium carbonate content of the sediments is relatively low, with two peaks of around 15% at elevations 1885 m and 1630 m, and 30% at elevation 1510 m. This is due to the presence of alternating thick layers of dark-gray, non-calcareous to slightly calcareous argillite and thin banks of calcareous-cemented sandstone with few foraminifera. The sediments encountered are argillites with fine sandy and sandstone layers corresponding in places to weak carbonate peaks. The drop in content is explained by the absence of marl and limestone in this interval and the drop in foraminiferal content. These formations have been replaced by mudstones and sandstones. On the other hand, the peaks observed are due to calcitic cement sandstones. The LEO-3X well formations were sedimented in an anoxic marine environment with variable continental influence. The lithological section shows three (3) facies grouped into



D : Depth ; L : Lithology ; L S : Log sonic ; R : resistivity ;

C : calcimetry ; G : Glauconite ; D C : carbonaceous debris

P : pyrite ; L I : litholigic interval

Figure 4. Litho-diagraphic log of sediment deposits in interval 4 of the LEO-3X well.

lithological intervals were delineated in the direction of sedimentation. Interval 1 consists of alternating argillite, limestone and marl. Sediments in this interval were deposited by settling. Interval 2: alternating argillite, sand and sandstone. This interval is dominated by sand. The sediments of this interval were deposited in an intermittent environment. Interval 3 consists of argillite. The sediments of this interval were deposited by settling in a fairly calm, deep environment.

3.2. Presence or Absence of Bedrock and Type of Organic Matter

Albian (2498 m - 2380 m)

The sediments of the 118 m-high Abien contain a good deal of organic matter (1.72% by weight on average). With an S2 of 6.47 mgHC/g rock. We therefore have the presence of source rock and type II kerogen. This source rock is capable of generating oil given these parameters of HI 373 mg HC/g TOC (Figure 5).

Cenomanian (2371 m - 2225 m)

These sediments, with a total height of 137 m, and only 18 m contain an average amount of organic matter (0.77% by weight on average). With an S2 of 2.79 mgHC/g rock. This indicates the presence of source rock and type II kerogen. This source rock is capable of generating oil with an HI of 360 mg HC/g TOC. 119 m of sediment is free of source rock (Figure 6).

Turonian (2216 m - 2198 m)

These 18 m-high sediments contain an average amount of organic matter (0.77% by weight on average). With an S2 of 2.22 mgHC/g rock, these sediments do not constitute a source rock (Figure 7).

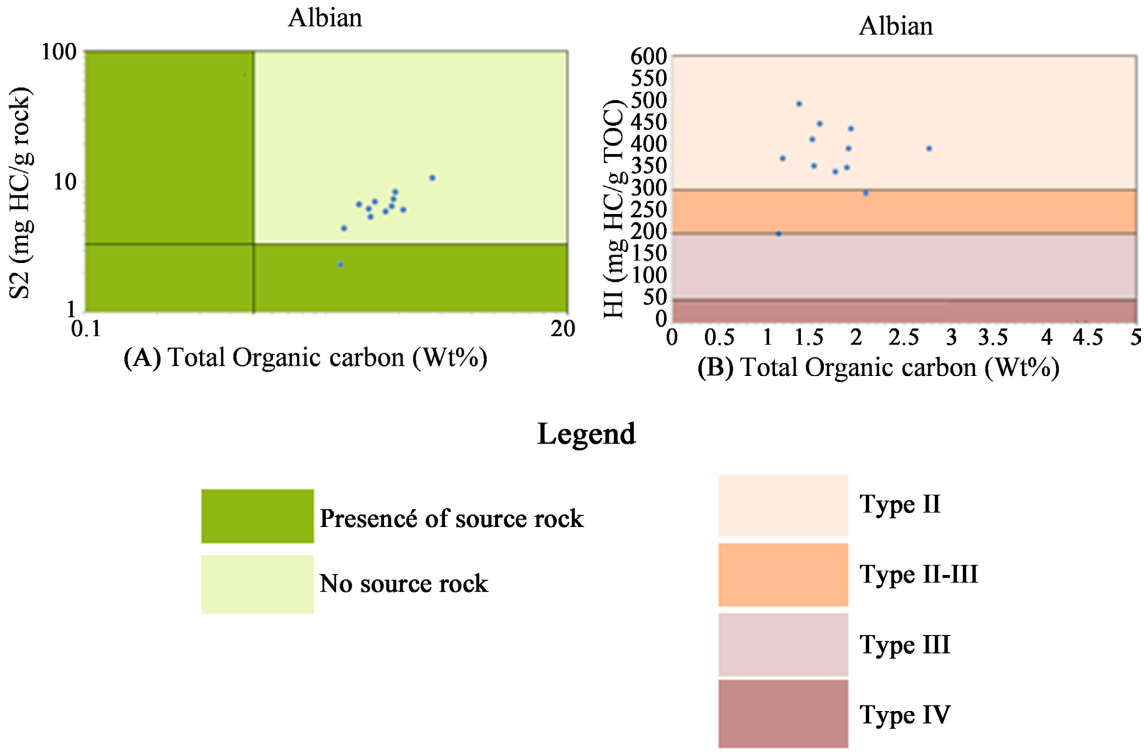


Figure 5. Diagrams for Albian sediments.

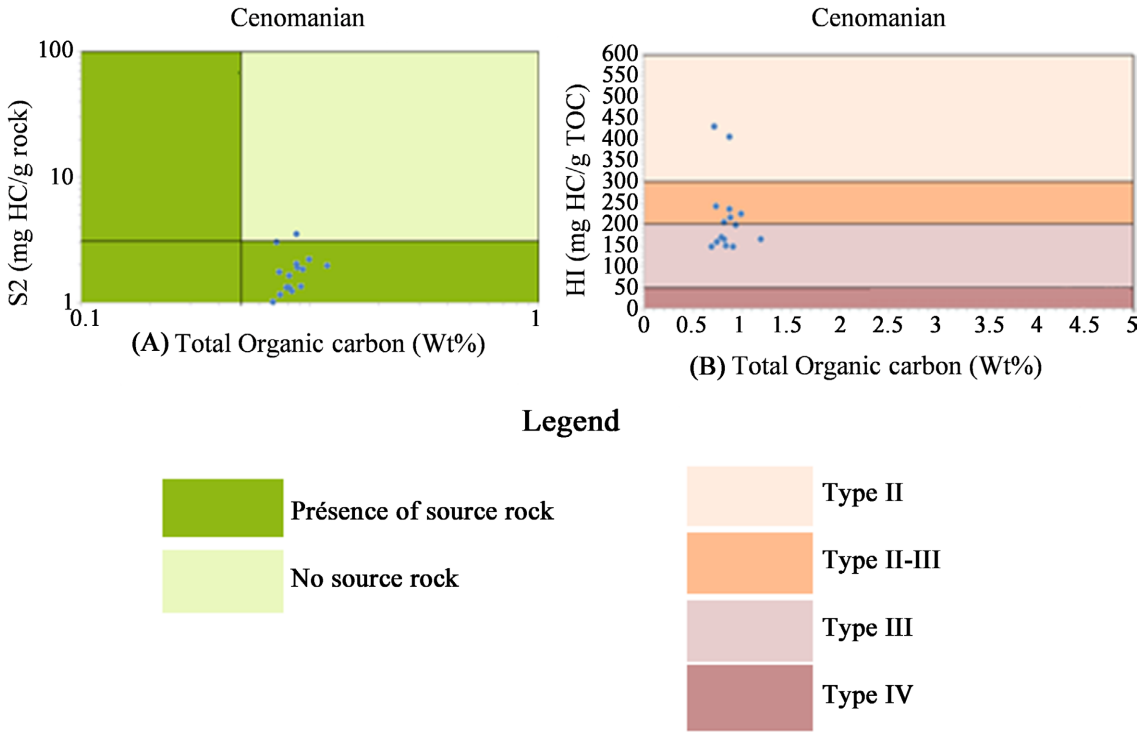


Figure 6. Diagrams for Cenomanian sediments.

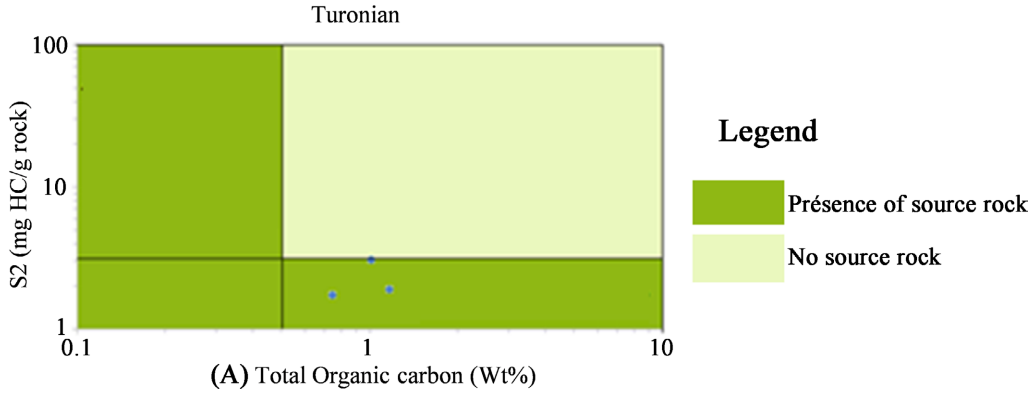


Figure 7. Turonian S2/TOC diagram.

Late Senonian (2188 m - 2097 m)

These sediments, with a total height of 91 m, contain a good quantity of organic matter (1.25% by weight on average). With an S2 of 3.12 mgHC/g rock, we can see the presence of bedrock and type II-III kerogen. This source rock is capable of generating a mixture of oil and gas with HI parameters of 249 mg HC/g TOC (**Figure 8**).

Campanian (2079 m-1786 m)

These sediments have a total height of 293 m.

- 2079 m - 2060 m: These sediments, 19 m high, contain an average amount of organic matter (0.793% by weight on average) and have an S2 equal to 2.42 mgHC/g rock. They do not constitute a source rock (**Figure 9**).
- 2051 m - 2015 m: With a height of 36m, these sediments contain a good

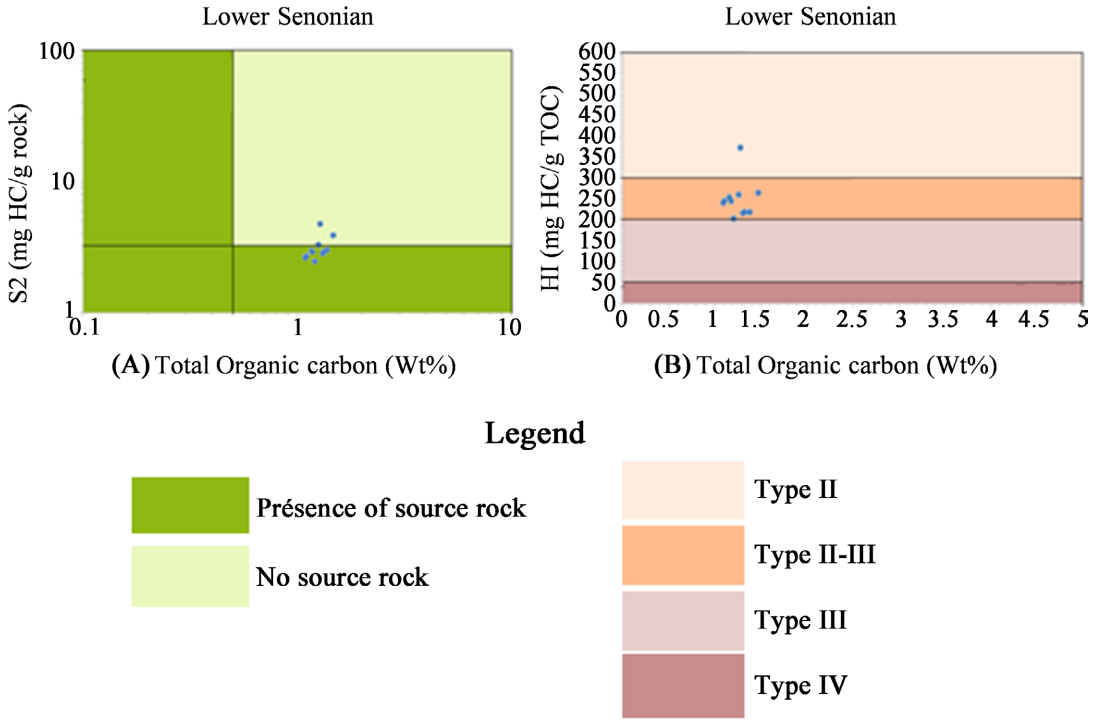


Figure 8. Diagram of Lower Senonian sediments.

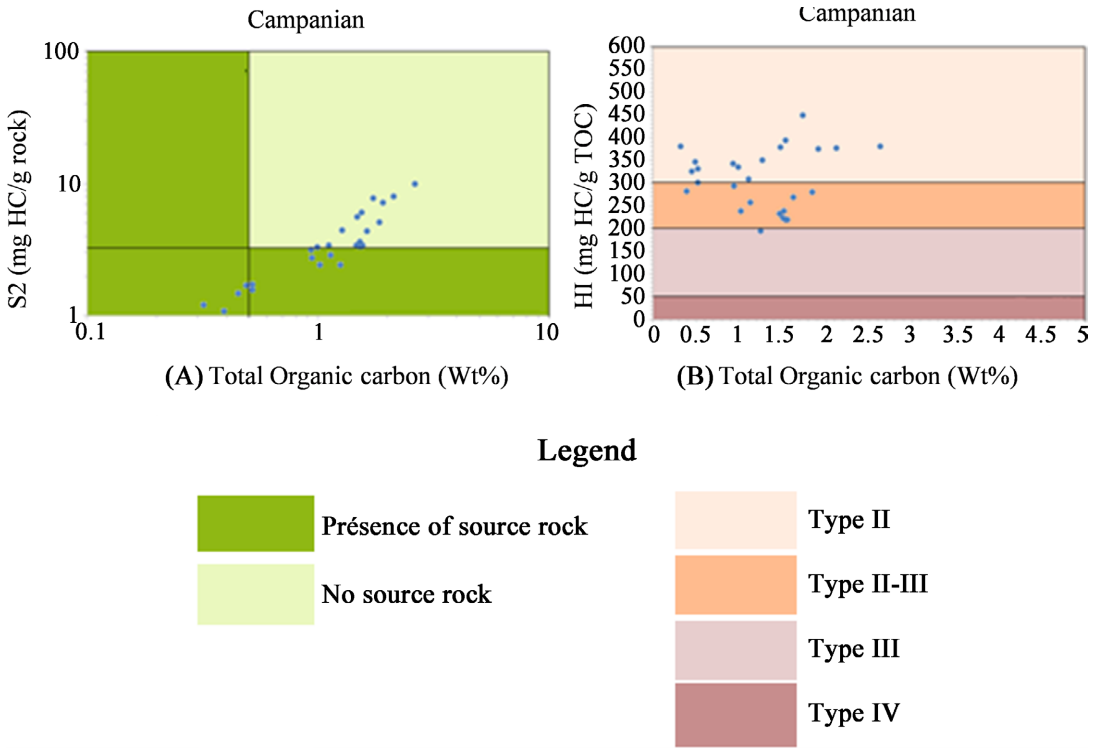


Figure 9. (A) S2/TOC and (B) HI/TOC diagrams for Campanian sediments.

quantity of organic matter (1.73% average weight). With an S2 of 6.53 mgHC/g rock. We therefore have the presence of source rock and type II-III kerogen. This source rock is capable of generating a mixture of oil and gas with HI

parameters of 239 mg HC/g TOC (Figure 9).

- 2006 m - 1914 m: These sediments, 92 m high, contain an average amount of organic matter (0.66% by weight on average). S2 is 2.20 mgHC/g rock. They do not represent a source rock.
- 1905 m - 1881 m: 24 m high, these sediments contain a good quantity of organic matter (1.92% average weight). They have an S2 equal to 7.67 mgHC/g rock. We therefore have the presence of source rock and type II kerogen. This source rock is capable of generating oil with HI parameters of 400.67 mg HC/g TOC (Figure 9).
- 1868 m - 1786 m: These sediments, 82 m high, contain a good deal of organic matter (1.6% by weight on average), with an estimated S2 of 3.45 mg HC/g rock. These data are characteristic of the presence of source rock and type II-III kerogen. This source rock is capable of generating a mixture of oil and gas with HI parameters of 237.77 mg HC/g TOC.

Maastrichtian (1777 m - 1402 m)

These sediments have a total height of 375 m.

- 1777 m - 1676 m: These sediments, 101 m high, contain very high levels of organic matter (2.02% by weight on average). With an S2 of 3.33 mgHC/g rock. We therefore have the presence of source rock and type II-III kerogen. This source rock is capable of generating a mixture of oil and gas with HI parameters of 255.62 mg HC/g TOC (Figure 10).
- 1667 m - 1494 m

173 m high, these sediments contain a very high level of organic matter

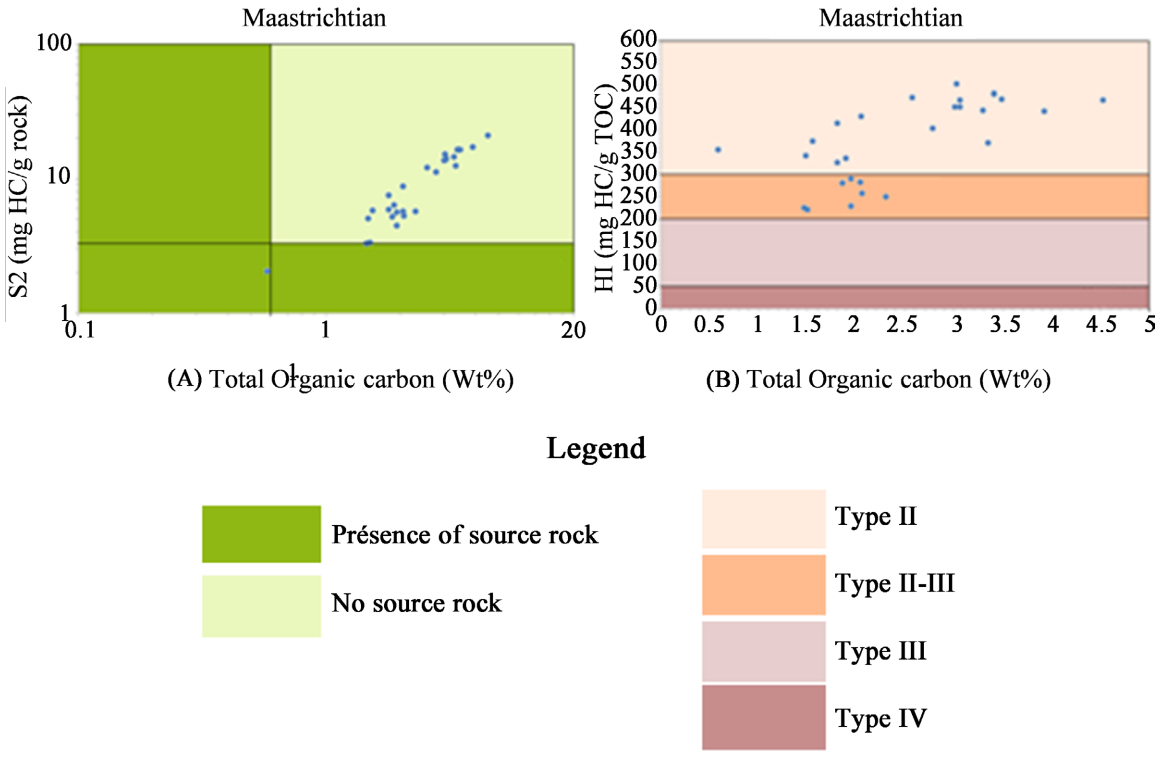


Figure 10. (A) S2/TOC and (B) HI/TOC diagrams for Maastrichtian sediments.

(3.19% by weight on average). With an S2 of 14.46 mgHC/g rock. We therefore have the presence of source rock and type II kerogen. This source rock is capable of generating oil with HI parameters of 452 mg HC/g TOC (**Figure 10**).

- 1475 m - 1402 m

With a height of 73 m, these sediments contain a good quantity of organic matter (1.80% by weight on average). With an S2 of 6.55 mgHC/g rock. We therefore have the presence of bedrock and type II kerogen. This source rock is capable of generating oil with HI parameters of 452 mg HC/g TOC (**Figure 10**).

4. Discussion

In the Albo-Maastrichtian interval, the average TOC content of the various stages ranges from 0.66% to 3.19% wt. These values show that the OM in well LEO3-X is of average to very good quantity. Good amounts of TOC are recorded in the Maastrichtian, Lower Senonian, Middle Campanian and Albian levels, while average TOC contents are observed in the rest of the study interval (Campanian, Turonian and Cenomanian). The high level of TOC in the interval could probably be linked to the anoxia marked by the presence of pyrite in the sediments. Anoxia is linked to the absence of oxygen in the water column. Indeed, if the bottom becomes anoxic or dioxin, the limit of the reducing environment within the sediment will rise towards the water-sediment interface and a good quantity of OM will be preserved. According to [9], in the case of sediments of continental origin and shallow basins, the oxygenation and redox conditions of the water column must be taken into account in the efficiency of organic matter preservation. These conditions play an important role in the preservation of organic matter and TOC, as do oxygenation conditions at the water-sediment interface [10]. If the water column is anoxic, organic matter will be less degraded during transport to the sediment [11] [12] [13]. Nevertheless, some authors [14] [15] [12] [16] [17] believe that water column anoxia has no effect on the long-term preservation of organic matter and TOC. On the other hand, average TOC levels (0.5% to 0.9% wt.) can be explained either by low organic inputs during sedimentation or by poor preservation of organic compounds due to oxidation phenomena within the sedimentation [18]. In the Ivorian sedimentary basin, this study highlighted the existence of type II kerogen and, exceptionally, mixed type II/III between the Albian and Maastrichtian. These results are in line with those obtained by [19] on the Ivorian continental shelf, where she characterized source rocks containing type II and III kerogen [20].

5. Conclusion

At the end of the sedimentological study coupled with this geochemical one, we can retain that the well LEO-3X is composed of several facies which are clays, sandstones, sands, marl and limestones but with clay dominance. The organic content of the interval studied is average to very good, with type II and II/III kerogen. Organic matter is predominantly of marine origin, and continental in places.

The source rocks identified in the LEO-3X well are disseminated throughout the well, with the exception of the Turonian, which has no source rock.

Given the importance of the source rocks identified, it would be interesting to know their petroleum potential as well as their maturity.

Acknowledgements

We would like to express our deep gratitude to PETROCI's General Management, particularly to the Centre d'Analyses et de Recherche (CAR), which enabled us to carry out all the analyses.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Rezaee, R. (2002) Petroleum Geology. Alavi Publication, Tehran, 479.

[2] Bamba, K.M., Digbehi, Z.B., Sombo, C.B., Goua, E.T. and N'da, V.L. (2011) Foraminifères planctoniques, biostratigraphie et paléoenvironnement des dépôts albo-turoniens de la Côte d'Ivoire, Afrique de l'Ouest. *Revue de Paléobiologie*, *Genève* (*Suisse*), **30**, 1-11.

[3] Kouassi, K.A. (2014) Episode anoxique à la limite C/T dans le bassin sédimentaire offshore de Côte d'Ivoire: Intérêt pétrolier des black shales. Thèse de Doc., Univ. F. H. Boigny, Abidjan, 239 p.

[4] Yao, K.C. (2014) Caractérisation des niveaux carbonates du Crétacé du bassin sédimentaire de Côte d'Ivoire: Implication paléoenvironnementale et intérêt pétrolier. Doctorat, Université Félix Houphouët Boigny, Abidjan, 228 p.

[5] Ouattara, B.I. (2017) Impacts de la crise biologique intermédiaire du Cénomanien-Turonien dans le golfe de Guinée: Cas du bassin sédimentaire de Côte d'Ivoire, à partir des études sédimentologique, géochimique et palynostratigraphique. Thèse de Doctorat, Université Félix Houphouët Boigny, Abidjan, 219 p.

[6] Kokoa, C.M.R. (2019) Chimiostratigraphie et potentiel pétrolier des sédiments de l'est de la marge d'Abidjan (bassin offshore de côte d'ivoire). Thèse de Doc., Univ. F. H. Boigny, Abidjan, 182 p.

[7] Kubler, B., Chagnon, A., Bertand, R., Achab, A. and Piltion, J.L. (1975) Potentiel pétoligène et évolution diagénétique. Institut National de la Recherche Scientifique, Rapport interne, 28 p.

[8] Marinho, M. and Mascle, I. (1987) Evoluçaoestructuralodel plato marginal da Guinéesuarelaçao com a formaçao do oceano Atlantico Centro-Equatorial. *Revista Brasileira de Geociencias*, **17**, 111-117. https://doi.org/10.25249/0375-7536.1987111117

[9] Pelet, R. (1983) Vers une sédimentologie de la matière organique. *Bulletin de la Société Géologique de France*, **7**, 483-493. https://doi.org/10.2113/gssgfbull.S7-XXV.4.483

[10] Tyson, R.V. (1995) Abundance of Organic Matter in Sediments: TOC, Hydrodynamic Equivalence, Dilution and Flux Effects. In: Tyson, R.V., Ed., *Sedimentary Organic Matter*, Springer, Berlin, 81-118. https://doi.org/10.1007/978-94-011-0739-6_5

[11] Glenn, C.R. and Arthur, M.A. (1985) Sedimentary and Geochemical Indicators of Productivity and Oxygen Contents in Modern and Ancient Basins: The Holocene Black Sea as the "Typé" Anoxic Basin. *Chemical Geology*, **48**, 325-354. https://doi.org/10.1016/0009-2541(85)90057-9

[12] Canfield, D.E. (1989) Reactive Iron in Marine Sediments. *Geochimica et Cosmochimica Acta*, **53**, 619-632. https://doi.org/10.1016/0016-7037(89)90005-7

[13] Hollander, D., Behar, F., Vandenbroucke, M., Bertrand, P. and Mckenzie, J.A. (1990) Geochemical Alteration of Organic Matter in Eutrophic Lake Greifen: Implications for the Determination of Organic Faciès and the Origin of Lacustrine Source Rocks. In: Hue, A.Y., Ed., *Deposition of Organic Faciès*, *Studies in Geology*, Vol. 30, American Association of Petroleum Geologists, Tulsa, 181-193. https://doi.org/10.1306/St30517C12

[14] Richards, F.A. (1976) The Enhanced Preservation of Organic Matter in Anoxic Marine Environments. In: Hood, D.W., Ed., *Organic Matter in Natural Waters*, Occasional Publication of the Institute of Marine Science, University of Alaska, Anchorage, Vol. 1, 399-411.

[15] Henrichs, S.M. and Reeburgh, W.S. (1987) Anaerobic Mineralization of Marine Sediment Organic Matter: Rates and the Role of Anaerobic Processes in the Oceanic Carbon Economy. *Geomicrobiology Journal*, **5**, 191-237. https://doi.org/10.1080/01490458709385971

[16] Jahnke, R.A. (1990) Early Diagenesis and Recycling of Biogenic Debris at the Seafloor, Santa Monica Basin, California. *Journal of Marine Research*, **48**, 413-436. https://doi.org/10.1357/002224090784988773

[17] Cowie, G.L., Hedges, J.I. and Calvert, S.E. (1992) Sources and Relative Reactivities of Amino Acids, Neutral Sugars, and Lignin in an Intermittently Anoxic Marine Environment. *Geochimica et Cosmochimica Acta*, **56**, 1963-1978. https://doi.org/10.1016/0016-7037(92)90323-B

[18] Espitalie, J., Deroo, G. and Marquis, F. (1986) La pyrolyse Rock-Eval et ses applications. Troisième partie. *Revue de l'Institut français du Pétrole*, **41**, 73-89. https://doi.org/10.2516/ogst:1986003

[19] Akobe, A.C. (2010) Caractéristique des grès de la Côte d'Ivoire et du Ghana (Golfe de Guinée): Environnement de dépôt, maturité et potentialité énergique (réservoir à hydrocarbure).Thèse Doctorat Unique Univ. Cocody, Cocody, 167 p.

[20] Ahoure, N.D., Goua, T.E., Oura, E.L., Coulibaly, A.S., Yao, N.J.P., Dobo, K., Kone, L., Fofana, B. and Digbehi, Z.B. (2020) Caractérisation Sédimentologique Et Géochimique Des Sédiments Albo-Maastrichtien Du Puits AH-1X Dans Le Bassin Sédimentaire De Côte d'Ivoire. *International Journal of Engineering Science Invention*, **9**, 18-25.