International Journal of Oil, Gas and Coal Engineering
2022; 10(2): 59-67
http://www.sciencepublishinggroup.com/j/ogce
doi: 10.11648/j.ogce.20221002.13
ISSN: 2376-7669 (Print); ISSN: 2376-7677 (Online)

Petrographic Specificity and Petroleum Potential of Neocomian Deposits in the Central Part of Dahomey Embayment (Benin)

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To cite this article:

Armand Kiki, Christophe Kaki, Gérard Alfred d'Almeida, Suzanne Amelina, Blandine Biaou. Petrographic Specificity and Petroleum Potential of Neocomian Deposits in the Central Part of Dahomey Embayment (Benin). *International Journal of Oil, Gas and Coal Engineering*. Vol. 10, No. 2, 2022, pp. 59-67. doi: 10.11648/j.ogce.20221002.13

Received: January 13, 2022; **Accepted**: February 10, 2022; **Published**: April 29, 2022

Abstract: The Dahomey Embayment, made up of a series of coastal basins, is one of the petroleum provinces of the Gulf of Guinea. Its central part, represented by the coastal sedimentary basin of Benin, contains sediments of Paleozoic to Late Quaternary age. The present study based on geological and geochemical data, analyzed by a multidisciplinary interpretative approach, aims at highlighting the petrographic specificities and the petroleum potential of the Neocomian age deposits of the Benin coastal basin. This approach made it possible to obtain significant results. Thus, the microscopic study of about ten samples of the formation revealed that it consists of clays, silty clays and sandstone. In addition to the presence of minerals indicating the metamorphic and magmatic origin of the sediments, certain clayey levels contain organic matter and others, particular stratifications that may favour the migration of hydrocarbons. The geochemical results from the pyrolysis at Rock-Eval6 of twenty-two clay samples showed that they are source rocks with a good petroleum potential (TOC between 0.35 and 3.36%) and mature with Tmax values between 435°C and 448°C. The kerogen of the source rock is of type II and II/III with S2 and HI values which vary respectively from 1.2 to 11.2mgHC/g rock and 102 and 518mgHC/g TOC. These results (petrographic and geochemical) show the specificities and petroleum potential of the Neocomian deposits in the Benin coastal sedimentary basin.

Keywords: Neocomian Deposits, Benin Coastal Basin, Organic Matter, Source Rock

1. Introduction

The Gulf of Guinea is a petroleum province made up of a series of basins including the Dahomey Embayment which occupies its northern part. This Embayment, which extends from Mount Okitipupa (Nigeria) to the Accra-Keta Basin (Ghana) through the coastal basins of Benin and Togo, has been the subject of intense oil exploration activities from the early 1950s to date. This work has led to the discovery of hydrocarbon deposits and/or showings in various formations in most of the Embayment basins [1, 2]. A part from the Turonian-Coniacian and Aptian-Albian deposits, which have proven oil potential in most of the Gulf of Guinea basins, the Neocomian deposits remain the least explored, especially in the Dahomey Embayment basins. But in the Ghanaian basins, modest reserves have been identified and hydrocarbon indices have been identified in the Togolese basin [1, 3, 4]. All scientific works carried out on the coastal sedimentary basin (BSC) of Benin, only Billman [5] and Saga [6] have superficially approached the lithological aspect of the Neocomian deposits and Kaki et al [7] have, by approaching the petroleum systems of the offshore BSC established correlatively with the Nigerian basin, the potential of the Neocomian. Since the Benin BSC was formed in the same geodynamic context as the above-mentioned Embayment counterparts, the Neocomian deposits (or Ise formation) could also have an oil interest. The present paper aims to point up this interest by highlighting the petrographic specificities and the petroleum potential of these deposits.

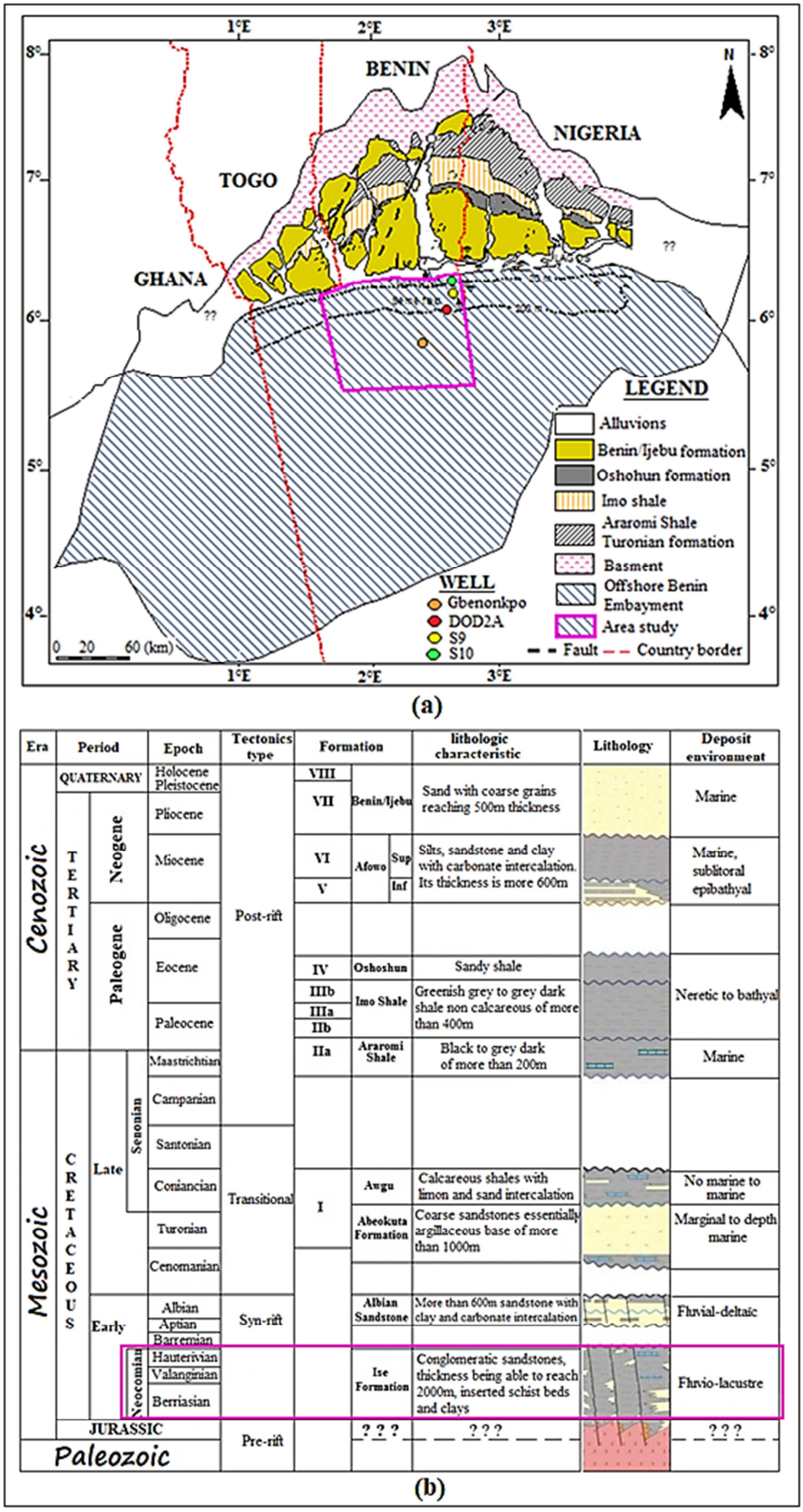


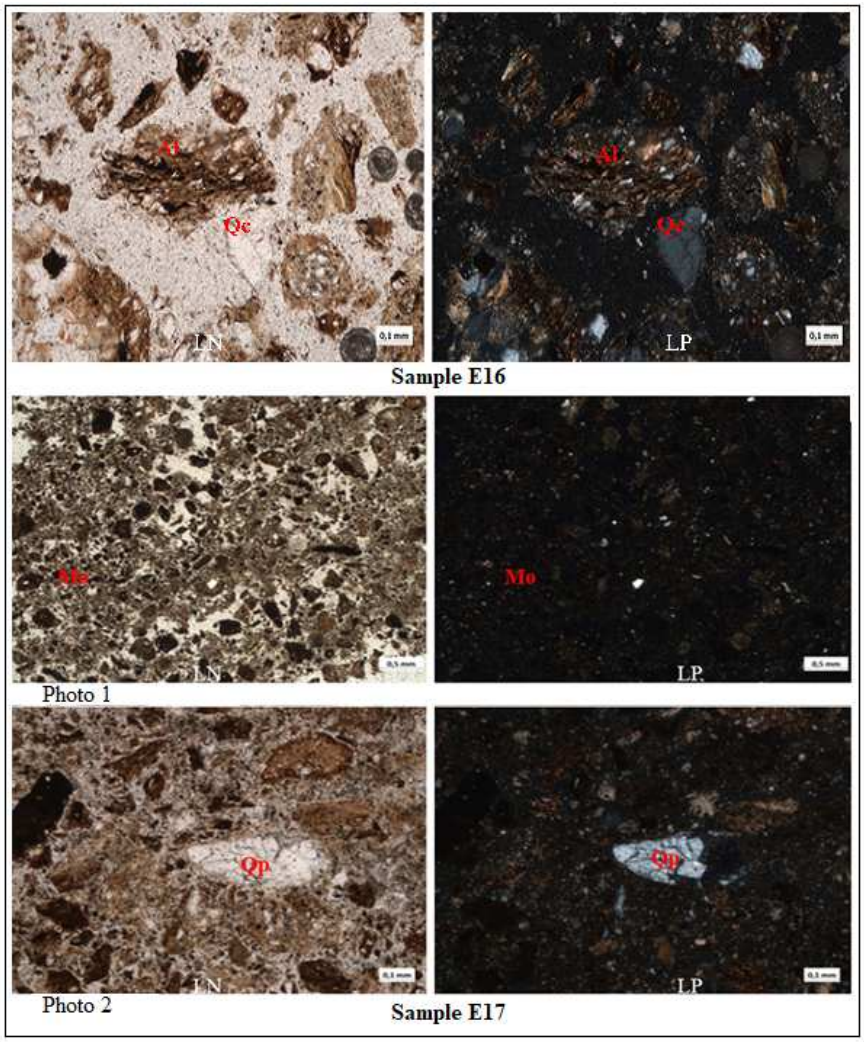
Figure 1. *Dahomey Embayment map showed the area study (a) and lithostratigraphic column of the BSC offshore part (b).*

2. Presentation of the Study Area

Meso-Cenozoic and probably Paleozoic age, the BSC of Benin occupies the central part of the Dahomey Embayment (figure 1a). It is located between parallels 3°00' and 7°30' North latitude and meridians 1°55' and 3°0 East longitude and includes an onshore and an offshore part. Its northern limit is marked by the outcrop zone of Precambrian basement (figure 1a). Geologically, four sedimentary sequences have been identified in the study area, in accordance with the tectono-sedimentary evolution of the Dahomey Embayment (figure 1b). These are pre-rift sequence; rift sequence (subdivided into Ise formation and albian formation) the intermediate sequence (subdivided into the Abeokuta and Awgu formations) and the drift sequence (with includes Araromi, Imo, Oshoshun, Afowo and Benin/Ijebu formations).

3. Methodological Approaches

It is based on the cross-interpretation of geological (rock samples), geochemical (Rock-Eval parameters). A total of twenty-nine (29) samples were collected from wells S9, S10 in the shallow offshore and GBENONKPO in the deep offshore. Part of the samples (seven) were used to produce thin section for the study of the petrographic characteristics of the formation. The second part, consisting of twenty-two (22) samples from wells S9 and GBENONKPO were analyzed at Rock-Eval6 as described in Behar an al [8]. The geochemical analysis results (Rock-Eval) are processed by Xlstat 2017 and interpreted according to the guide described by Peters [9] to highlight the potential of the Ise formation sources rocks. In addition, the well-well correlation of the log profiles of wells S9, S10 and DOD2A constructed from the raw data log allowed to highlight the distribution of potential reservoir levels within the Ise formation. It should be noted that the petrographic analyses were carried out at the Laboratory of Geology, Mines and Environment (LaboGME) of the Abomey-Calavi (Benin) University and the geochemical analyses at the Centre of Analyses and Research (CAR) of PETROCI in Abidjan (Côte d'Ivoire).



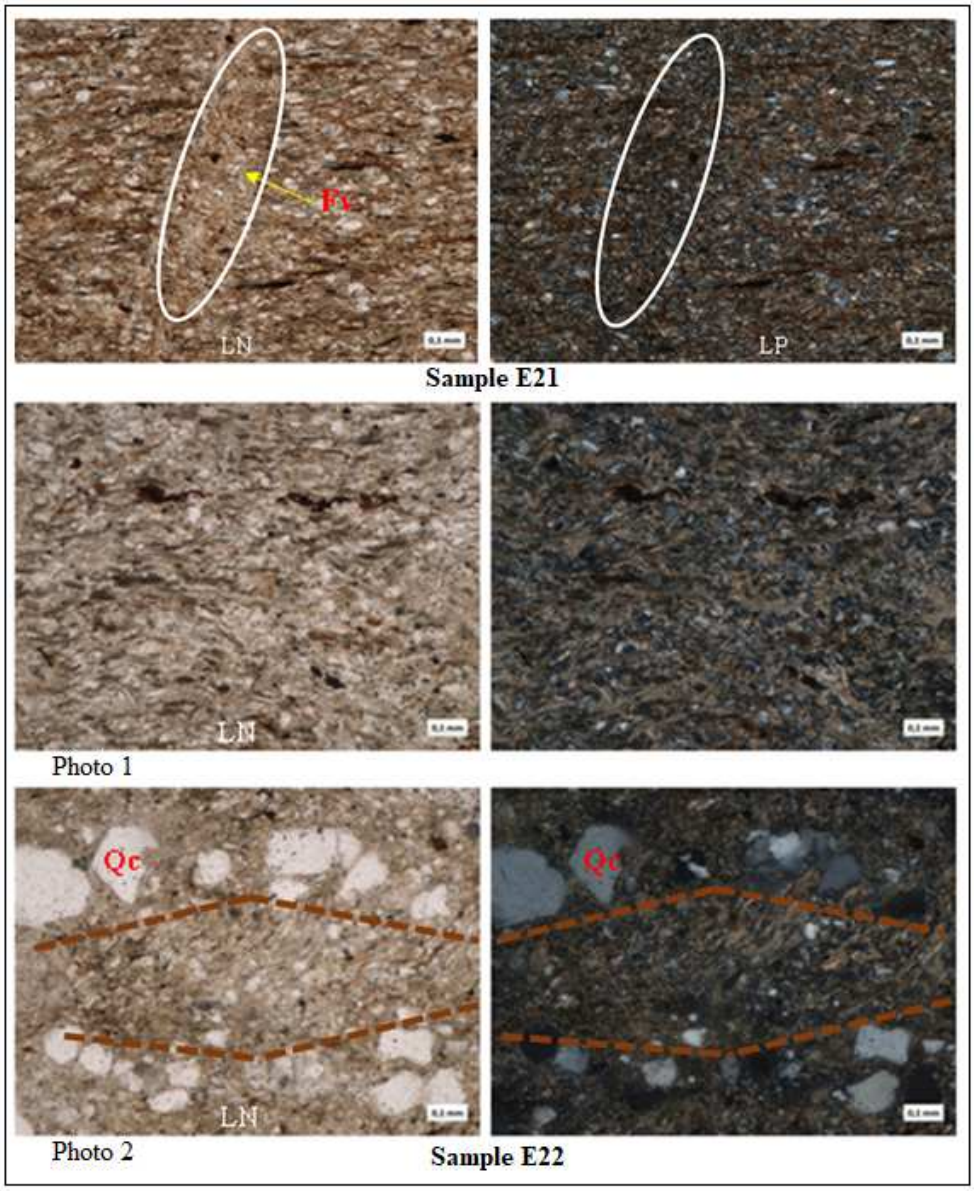
Q: quartz; Qc: corroded quartz; Al: Aleurite fragment; Mo: organic matter; Qp: polycrystalline quartz.

Figure 2. *Microphotographs of the clay sample (E16) and clay-limestone sample (E17) of the Ise formation in natural (LN) and polarized (LP) light.*

4. Results

4.1. Petrographic Characteristics of the Ise Deposits

Seven thin slides made from cuttings of the formation were analyzed. They are samples E16-E17 (well S9), E18-E19 (well S10) and E21, E22, E24 (well GBENONKPO). Plate 1 below shows the microphotography of the thin slide of the E16 sample taken in well S9 at 3100m. The study of this slide shows that it is a white-clayey rock with a kerogen-clay matrix. It is saturated to various degrees by organic matter. It contains quartz crystals, aleurite fragments, biotite flakes and genuine minerals such as calcite (figure 2). Quartz crystals ranging from 0.1 to 0.15mm in diameter are variously rounded. On the other hand, the E17 sample taken at 3140m in the same shaft shows rock fragments ranging in size from 0.01-0.05 to 0.3mm (figure 2- photo 1 and 2). This sample is composed of calcaro-earth clays, siliceous clays and aleuritic gaizes. The calcaro-earth clay (marl) unequally saturated in organic matter is composed of thin layers of dark brown color of 0.01-0.02 × 0.05mm (figure 2-photo 1). The aleuritic gaizes with a clay-siliceous matrix are composed of clasts (15%) with a diameter between 0.01-0.03 mm and contain clusters of organic matter with a diameter equal to 0.1 mm (figure 2-photo 2). Among these clasts, one finds crystals of quartz and feldspar.



Fv: plant fragment; Qc: corroded quartz.

Figure 3. *Microphotographs of the clay-silty sample (E21) and (E22) of the Ise formation in natural (LN) and polarized (LP) light.*

Furthermore, the analysis of the slides taken from GBENONKPO well samples E21 and E22 reveals that sample E21 taken between 2750-2760m is a clayey-silty rock saturated with dark brown organic matter films, containing

inclusions of clastic material and a thin plant fragment (figure 3). Microphotography of the slide reveals a clayey mass in which small crystals of quartz and feldspars with diameters varying between 0.008 and 0.05mm are embedded. The same observations with a few differences are made on the thin slide of the E22 sample taken between 2800 and 2810m. The difference is notably relative to its richness in carbonaceous elements (figure 3-photo 1) and to the stratification observed (figure 3-photo 1). Also, the quartz grains, rounded to sub-rounded, with diameters ranging from 0.01 to 0.05mm and feldspar crystals (orthose and plagioclase) are well individualized (figure 3-photo 2).

4.2. Petroleum Specificity

While the seismic data estimates the thickness of the Ise formation at more than 2000 m [6], the drilled formation varies from 77 m (S10 well) to 394 m (GBENONKPO well). Twenty-two samples from the clayey (and/or shale) levels of the formation were analyzed at Rock-Eval6 (figure 4). The results from the samples analysis are summarized in the following table.

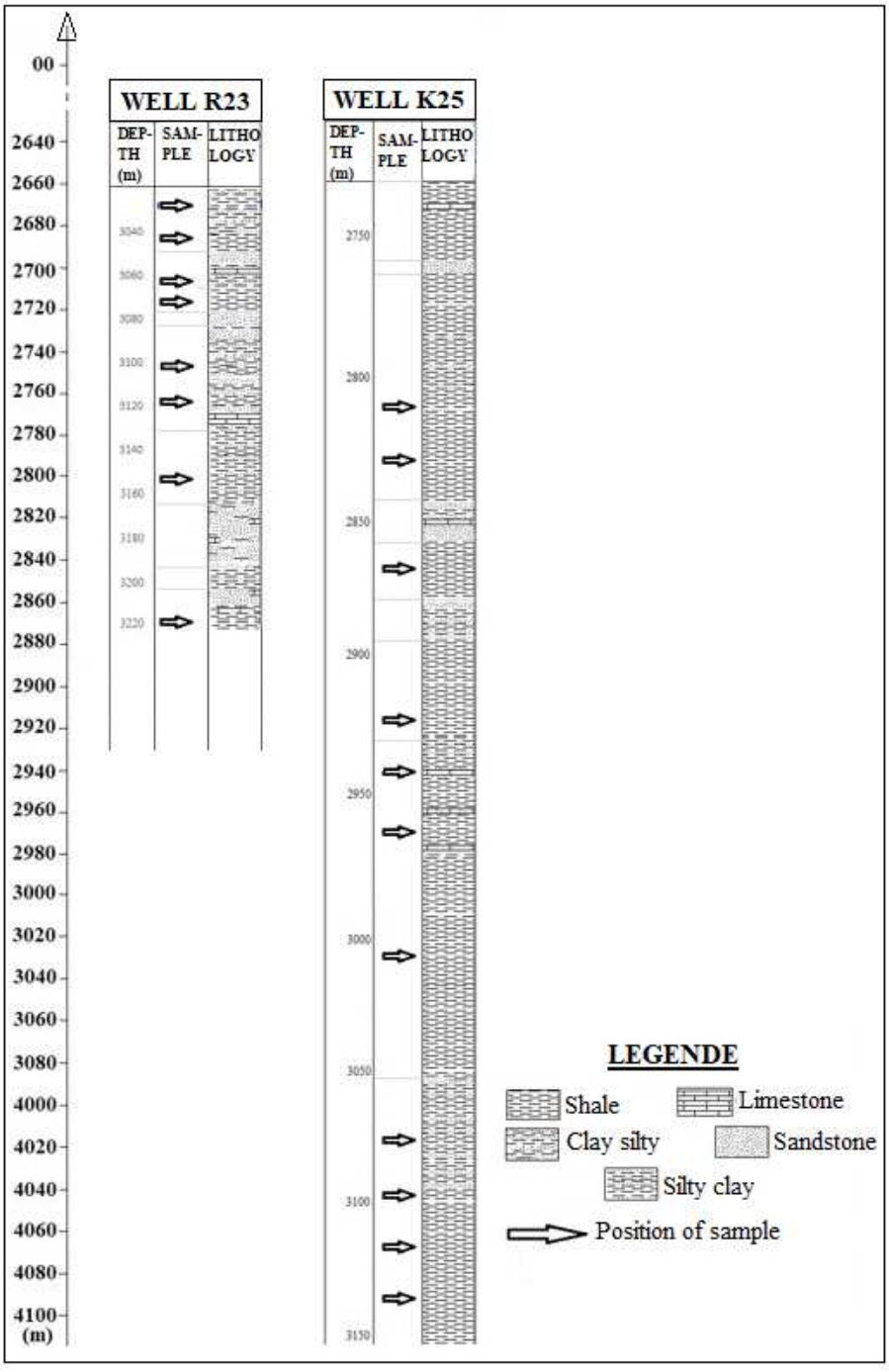


Figure 4. *Lithological sections of wells with indication of the levels sampled for geochemical analyses.*

Table 1. *Rock-Eval parameters of the Ise Formation samples.*

Well	Codes/Depth (m)	Mesuared parameters				Calculated Parameters				
		S1 (mg HC/g rock)	S2 (mg HC/g rock)	S3 (mgCO_2/g rock)	Tmax (°C)	HI (mg HC/g TOC)	OI (mg CO_2/g TOC)	PI	TOC (%)	S2/S3
Gbenonkpo	D1 (2750)	0,05	4,72	0,51	437	372	40	0,01	1,27	9,25
	D2 (2810)	0,04	1,28	0,4	438	361	114	0,03	0,35	3,2
	D3 (2830)	0,07	4,63	0,36	444	358	28	0,02	1,29	12,86
	D4 (2840)	0,06	8,06	0,46	443	486	28	0,01	1,66	17,52
	D5 (2850)	0,05	5,8	0,37	441	479	31	0,01	1,21	15,68
	D6 (2860)	0,07	11,2	0,49	442	518	23	0,01	2,16	22,86
	D7 (2920)	0,05	3,75	0,32	443	401	34	0,01	0,94	11,72
	D8 (2960)	0,05	4,73	0,37	439	397	31	0,01	1,19	12,78
	D9 (2980)	0,06	5,51	0,44	440	393	31	0,01	1,4	12,52
	D10 (3000)	0,06	3,22	0,41	443	335	42	0,02	0,96	7,85
	D11 (3090)	0,04	2,34	0,24	446	296	30	0,02	0,79	9,75
	D12 (3110)	0,04	1,71	0,3	444	286	49	0,02	0,6	5,7
	D13 (3130)	0,04	1,51	0,25	446	249	41	0,03	0,61	6,04
	D14 (3200)	0,03	2,64	0,19	445	375	27	0,01	0,7	13,89
S9	D15 (3026)	0,04	1,63	0,47	438	164	47	0,02	0,99	3,49
	D16 (3045)	0,1	3,99	0,91	446	119	27	0,02	3,36	4,38
	D17 (3065)	0,08	2,94	0,77	443	120	31	0,03	2,45	3,82
	D18 (3075)	0,07	3,23	0,79	448	121	30	0,02	2,66	4,09
	D19 (3105)	0,08	3,1	0,73	445	133	31	0,03	2,33	4,25
	D20 (3120)	0,08	3,85	0,77	439	122	24	0,02	3,16	5
	D21 (3155)	0,09	3,24	1,31	435	102	41	0,03	3,19	2,47
	D22 (3225)	0,03	1,2	0,48	440	233	94	0,02	0,51	2,5

4.2.1. Petroleum Potential of the Ise Formation

It was evaluated by combined analysis of the TOC (Total Organic Carbon) values and those of the S2 peak (quantity of non-volatile hydrocarbons generated during pyrolysis). The analysis of Rock-Eval result shows that except for samples D2 and D23, all the others have TOC values ranging from 0.6 (D12) to 3.36% (D16) while the S2 values vary from 2.34 (D11) to 11.2 mgHC/g rock (D12) except those of samples D2, D12, D13, D15 and D22 for which they are lower than 2 mgHC/g rock. As shown by the distribution of the samples in the S2 versus TOC diagram (figure 5), the Ise formation remains a relatively good source rock with good petroleum potential despite the few low TOC and S2 values in some samples.

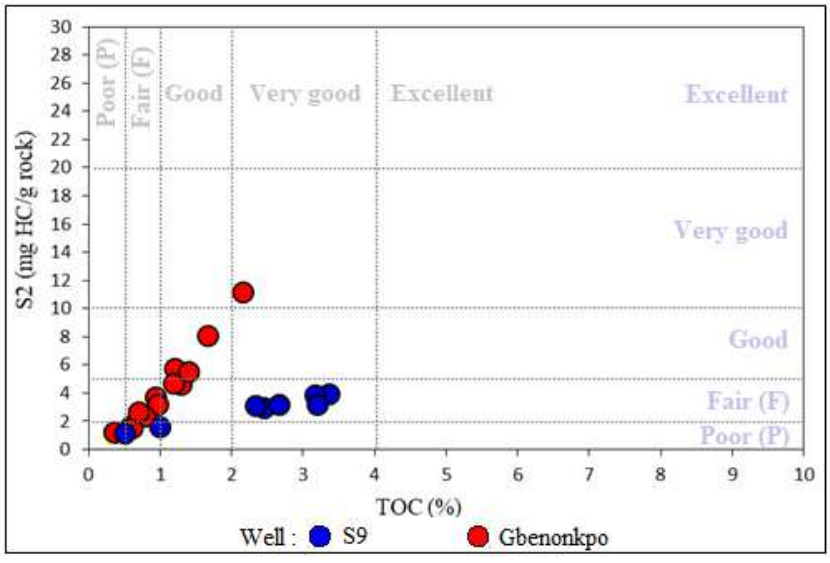


Figure 5. *Diagram S2 versus TOC indicating the hydrocarbon potential and capacity of the source rock of the Ise Formation.*

4.2.2. Type of Organic Matter

Hydrogen Index values for samples D1 to D10 and D14 (GBENONKPO well) between 335 (D10) and 518 (D6) mgHC/g TOC are greater than 300 mgHC/g TOC and less than 600 mgHC/g TOC. This indicates the presence of Type II kerogen. However, the higher S2/S3 ratio (15.68 to 22.86) of some of these samples (D4, D5 and D6) at 15 is more indicative of the presence of type II/I kerogen. On the other hand, samples (D11 to D15) from the GBENONKPO well and D22 from well S9 with HI values greater than 200 mgHC/g TOC ranging from 249 (D13) to 296 mgHC/g TOC (D11) indicate mixed type II/III kerogen. Also, Hydrogen Index (HI) values ranging from 102 (D21) to 164

mgHC/g TOC (D11) and S2/S3 values ranging from 2.47 (D21) to 5 (D20) indicate the presence of a type III kerogen. Thus, the clay and/or shale levels of the Ise Formation contain kerogens with a dominance of type II kerogen. The dominance of this type of kerogen is confirmed by the distribution of Hydrogen Index values in the HI versus OI diagram (figure 6).

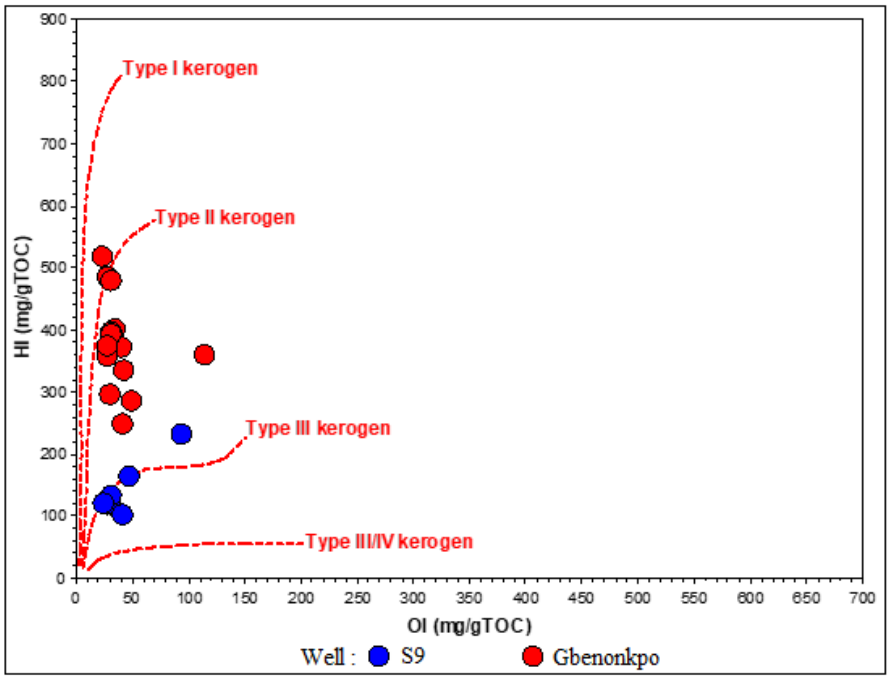


Figure 6. *HI versus OI diagram showing the kerogen types of the Ise formation.*

4.2.3. Thermal Maturity of Organic Matter

The primacy of all the S2 values of the samples analyzed at 0.2 mgHC/g rock correlates with the thermal maturity (Tmax) values obtained. Sources rocks containing the above-mentioned kerogen types are considered mature when the Tmax value is above 435°C. Thus, of all the samples analyzed, only sample D21 (well S9) taken at 3155 m has a Tmax equal to 435°C, thus at the limit of maturity. All the others have a Tmax value higher than the maturity limit and between 437 (D1) and 448°C (D18). As a result, all the samples analyzed are mature. Furthermore, the analysis of the Van Krevelen (Espitalié) Tmax versus Base-Depth diagram (figure 7) shows that all analysed samples are in the Oil window. Maturity is reached at a depth of 2750m for the samples from the GBENONKPO well versus 3026m for those from the S9 well.

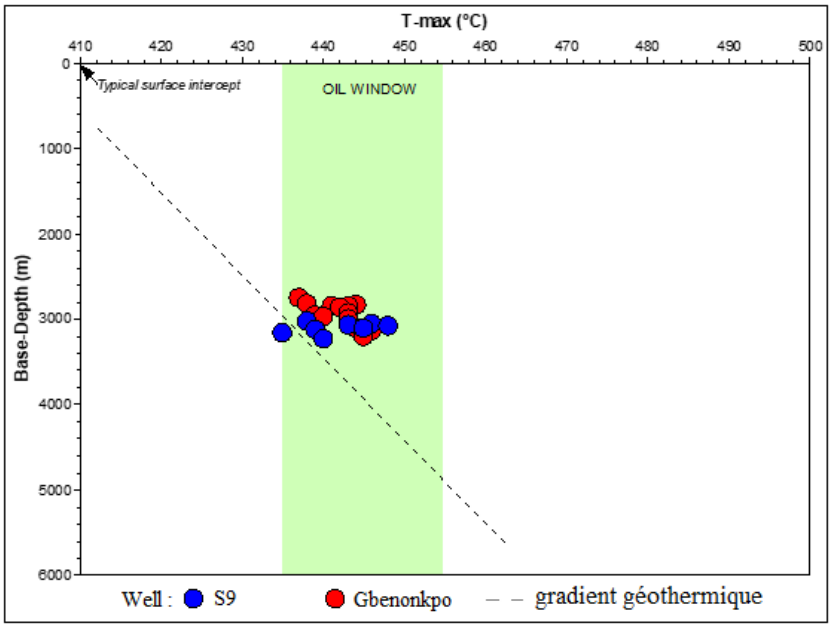


Figure 7. *Base-Depth versus Tmax diagram showing the degree of maturity of the Ise formation.*

5. Discussions

Microscopy of a few samples showed that they are clayey, clayey-silty or silt-clayey rocks with varying degrees of organic matter. The angular to sub rounded shape of the quartz grains with a remarkable dominance of angular grains in the sediments reflects a relatively short distance transport. Also, the presence of certain minerals such as garnet indicates a metamorphic origin of the sediments. All these elements in conjunction with the phenomena that led to the opening of the basin indicate that the Neocomian deposits are composed of fragments (or debris) of crystalline rocks (magmatic and metamorphic) resulting from the denudation of the basement and the formation of the gravels as indicated in the work of [1, 5, 6, 10].

On the geochemical level, the results of the Rock-Eval6 analysis of the samples (clay levels) of the Ise formation show high values of TOC (from 0.35 to 3.63%) and S2 (from 1.2 to 11.2mgHC/g rock) which reflect the good petroleum potential of these source rocks. These results support and confirm those of IPL [11] based on the pyrolysis of a sample of the Ise formation collected at 3160 m in well S9 with a TOC value of 3.8%. The same is true for samples from the Ise-2 well in the Aje field of the Nigeria Basin where Haack's average TOC value is 4% [12]. Also, in the Potiguar Basin of Brazil, the counterpart of the BSC of Benin on the other side of the Atlantic Ocean, an average TOC of 4% was also reported for the Neocomian (Lower Cretaceous) Pendência Formation [12, 14]. On the other hand, the different values of the Hydrogen Index (from 102 to 518 mgHC/g TOC) of the samples indicate that the source rocks of the Ise Formation contain mostly type II and III kerogen. These results provide more insight into the type of organic material contained in the formation than previous work, which estimated that the Ise Formation contains Type I kerogen on a correlative basis with the Neocomian formation in the Aje oil field in Nigeria [7]. While in the Nigerian Basin, Haack [11] reported Type I and I/II kerogen in the Ise (Neocomian) formation because of HI values well above 500 mgHC/g TOC. Trindade [13], reported in the Pendência (Neocomian) formation of the Potiguar Basin of the South American margin, the predominance of kerogen types I and II. This variation in kerogen type between synergistic basins is explained by the variation in the sources of organic matter. Tmax values between 435 and 448°C allow to consider the source rocks of the formation mature and likely to generate oil. Indeed, no Tmax value of the samples analyzed is lower than 435°C and is in the range of 455°C to 465°C considered as respective limit values of the oil window of the source rocks containing kerogen types II and III [15]. The increase in Tmax values with depth and the decrease in HI values noted for some samples (D2, D3, D9 to D11) could be related to their increasingly coarse granularity with depth.

6. Conclusion

This study of the Neocomian deposits (Ise formation) of the offshore of the coastal sedimentary basin of Benin, based on the combined interpretation of the results of petrographic and geochemical analyses, allowed to show its lithofacial specificities and its oil potential. The microscopic study associated with the interpretation of diagrammatic profiles showed that these deposits are made up of clay and sandstone (or sand) levels. In addition, the microscopic study of certain clay levels indicated that they are sometimes silty clays containing organic matter in places. The results of the Rock-Eval pyrolysis of these levels revealed that the Ise formation contains mature source rocks (Tmax between 435 and 448°C) with good petroleum potential. These source rocks contain kerogen types II and II/III with TOC and S2 values ranging from 0.35 to 3.36% and 1.2 to 11.2 mgHC/g rock and Hydrogen Index values ranging from 102 to 518 mgHC/g TOC respectively.

Acknowledgements

This article is the result of active cooperation between the Geology, Mines and Environment Laboratory of UAC and the Ministry of Water and Mines of Benin through the Directorate of Hydrocarbons and other Fossil which provided the raw data used on the one hand and the Analysis and Research Centre of PETROCI (Abidjan) where analyses were carried out on the other hand. Our thanks to the persons in charge of these different structures.

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