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Comportement géochimique des séquences de 3è ordre des dépôts albiens à l'Est de la marge d'Abidjan (Bassin sédimentaire de Côte d'Ivoire)

[Geochemistry behavior of the sequence stratigraphy of 3rd order of the Albian deposits on east of the Abidjan margin (Sedimentary Basin of Côte d'Ivoire)]

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ABSTRACT: The geochemical study of the sequences of 3rd order of the East of the margin of Abidjan permitted to identify the source rocks of the albian deposits. The pyrolytic methods applied to 30 samples of cuttings, from the drillings Freedom 1 and 2, revealed three types of organic matter at the early of maturity, the types III, II/III and II in the sequences. The variation of the origin of the organic matter in the systems tracts of the sequences testifies a change in the environment of deposit in phase with the eustatic fluctuations. The passage from the type III or II/III to the type II, eventually coupled with a rise of the values of the TOC and/or S2, in this study, evokes a rise in the marine level which would support the good conditions of safeguarding of the organic matter. The albian source rocks in the drilling Freedom 1 are bad source rocks whereas those in the drilling Freedom 2 are good producing source rocks of oil and/or gas hydrocarbon.

KEYWORDS: Organic geochemistry, sequence stratigraphy, source rock, Albian, Côte d'Ivoire.

RÉSUMÉ: L'étude géochimique des séquences de 3eme ordre de l'Est de la marge d'Abidjan a permis d'identifier les roches mères des dépôts albiens. Les méthodes pyrolytiques appliquées à 30 échantillons de sédiments, issus des puits Freedom 1 et 2, ont révélé trois types de matière organique en début de maturité, les types III, II/III et II dans les séquences. La variation de l'origine de la matière organique dans les cortèges de dépôt des séquences témoigne d'un changement d'environnement de dépôt en phase avec les fluctuations eustatiques. Le passage du type III ou II/III au type II, éventuellement couplé à une hausse des valeurs du COT et/ou du S2, dans cette étude, évoquent une élévation du niveau marin qui favoriserait les bonnes conditions de préservation de la matière organique. Les roches mères albiennes dans le puits Freedom 1 sont de mauvaises roches mères alors que celles dans le puits Freedom 2 sont de bonnes roches mères productrices d'hydrocarbure à huile et/ou gaz.

MOTS-CLEFS: Géochimie organique, séquence stratigraphique, roche mère, Albien, Côte d'Ivoire.

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1 INTRODUCTION

Organic matter is a material produced by alive beings (animals, vegetables, micro-organisms). It constitutes living and dead biomass. Its abundance in sediments depends on several factors including organic production, redox conditions, sediments grain size and sedimentation rate. A very fast sedimentation reduces considerably the bioturbation and the degradation of organic matter (OM) by aerobic bacteria. This sedimentation is controlled by eustatism and tectonics. This sedimentation is controlled by eustatism and tectonics. The preservation of the organic matter, which is mainly done in argillaceous sediments, must have a minimum rate of 0.5 weight % in order for these sediments to be qualified as source rocks [1].

The identification of the source rocks in sedimentary basins therefore appears to be essential for the understanding of the functioning of the petroleum system. In the Côte d'Ivoire, the Middle Cretaceous represents the period of interest for the National Society of Petroleum Operations of Côte d'Ivoire (PETROCI) [2]. The recent work of [3] allowed to establish the stratigraphic sequences of the Albian deposits of the offshore drillings, Freedom 1 and Freedom 2, in the ivorian sedimentary basin. But, what are the chemical characteristics of the source rocks present in the sequences identified in these two petroleum wells? The objective of this work is to identify possible elements of the petroleum system, particularly the source

2 MATERIAL AND METHODS OF STUDY

Thirty cuttings samples of two offshore drillings (Figure 1) were analyzed by Rock-Eval 6 pyrolysis of the Analyses and Research Center of PETROCI. The method study consists in evaluating [4], [5], [6] the petroleum potential of the rocks by the measurement of total organic carbon (TOC) and S2 (Table 1). The origin of the organic matter is given by the Hydrogen index (HI) and the thermal maturation by the temperature pyrolysis (Tmax).

Table 1. (a) Generative potential (quantity) of immature source rock, (b) kerogen type and expelled products (quality), and (c) thermal maturity [7]

Potential (quantity)	**TOC (wt %)**	**S2 (mg hydrocarbon/g rock)**
Poor	< 0.5	< 2.5
Fair	0.5-1	2.5-5
Good	1-2	5-10
Very good	2-4	10-20
Excellent	> 4	> 20
(a)		
Kerogen (quality)	**Hydrogen index (mg hydrocarbon/g TOC)**	
I	> 600	
II	300-600	
II/III	200-300	
III	50-200	
IV	< 50	
(b)		
Maturity	Tmax (° C)	
Immature	< 435	
Mature		
Early	435-445	
Peak	445-450	
Late	450-470	
Postmature	> 470	
(c)		

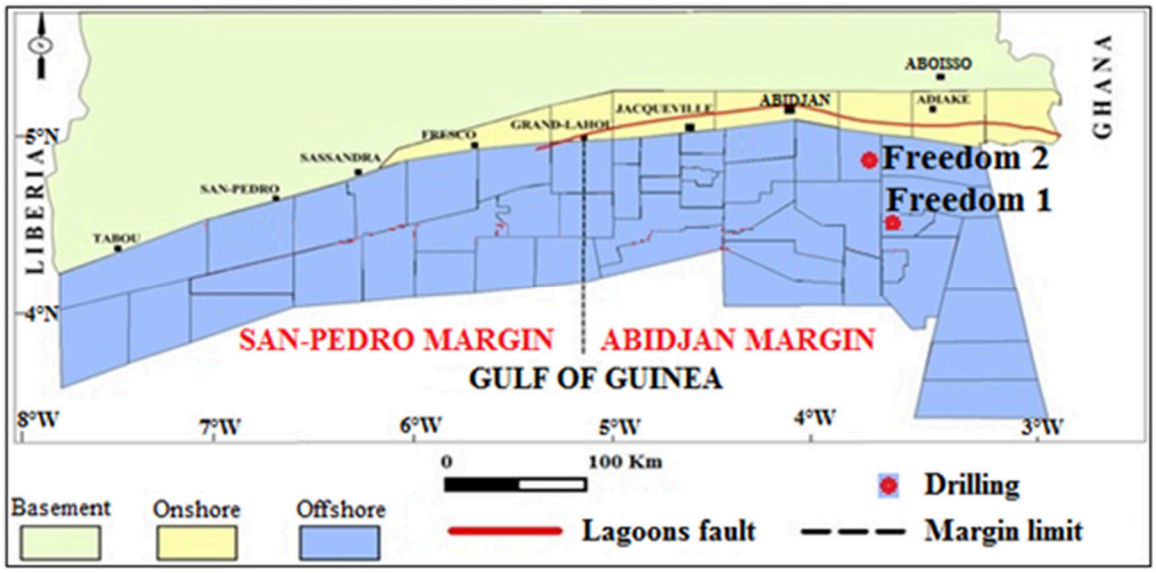

Fig. 1. Location of drilling sites

3 RESULTS

3.1 FREEDOM 1

The Albian interval in this well is composed of three sequences (ANO et al., 2018) : the sequences Al3 (4132 m – 4005 m), Al7 (4005 m – 4002 m) and Al8 (4002 m – 4000 m). Among these sequences, only the sequence Al3 is well known because of its thickness which is very significant. The Rock-Eval analyses (Table 2) indicate that the organic matter (OM) are at the early maturity because the Tmax oscillates between 436 C and 440 C (Figure 2).

Table 2. Rock-Eval pyrolysis results of Freedom 1

Age	Sequence stratigraphic [3]	System tract [3]	Depth (m)	S2	Tmax	HI	TOC
Albian	Al7 Top	SB Al8	4002	2.75	438	310	0.89
	Al3	HST	4008	2.2	439	326	0.67
			4014	1.46	437	206	0.71
			4020	1.24	438	266	0.47
			4026	1.59	437	240	0.66
			4032	0.8	440	189	0.43
			4038	0.78	436	168	0.47
			4044	1.42	437	267	0.53
		TST	4068	1.27	439	211	0.6
			4074	1.24	440	214	0.58
			4104	0.82	436	184	0.45
			4110	1.39	439	264	0.53
			4116	0.51	438	134	0.38
			4122	0.52	438	125	0.42
			4128	0.57	439	119	0.48
			4132	0.56	439	146	0.39

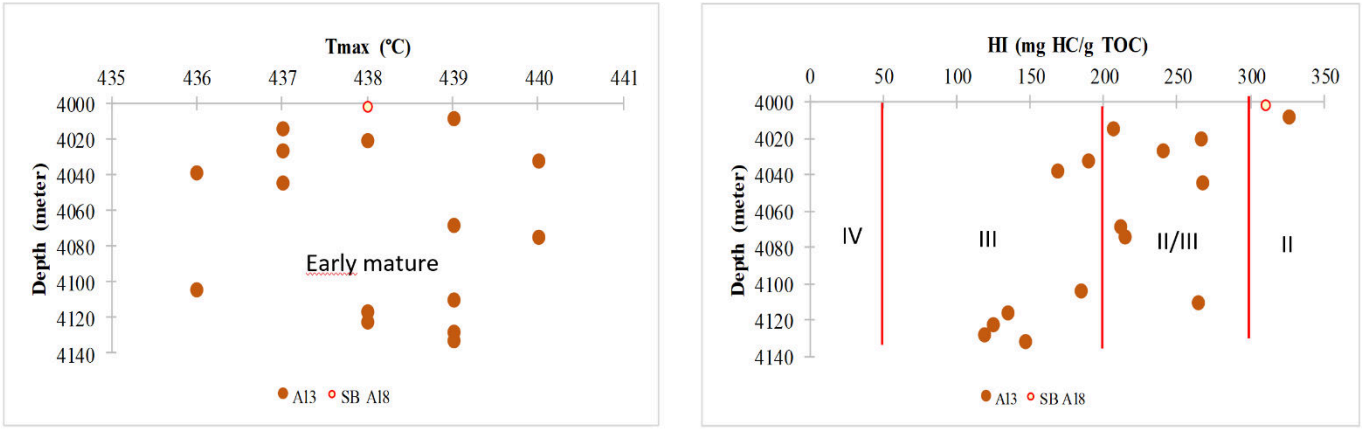

Fig. 2. Curve of evolution of Tmax (a) and the HI (b) according to the depth of Albian deposits in the well Freedom 1

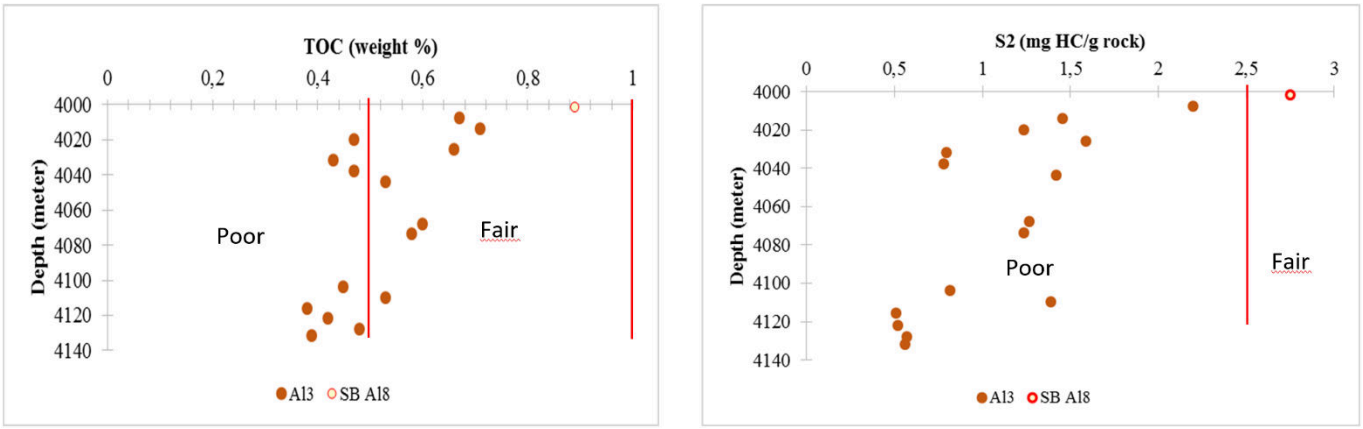

Fig. 3. Curve of evolution of TOC (a) and the S2 (b) according to the depth of Albian deposits in the well Freedom 1

The sequence Al3 at the base of this well is characterized by two systems tracts [3]: the transgressive system tract (TST, between 4132 m and 4050 m) and the highstand system tract (HST, from 4050 m to 4005 m). The organic matter content in the rocks of this sequence is poor to fair (Figure 3) with a poor petroleum potential (S2 < 2.5 mg HC/g rock). Generally, the rocks of the TST in this sequence are less enriched in OM than the rocks of the HST. The hydrogen index values show an evolution of the organic matter type from the base of the TST towards the top of the HST. The organic matter evolves from the type III to the type II while passing by the type II/III (Figure 2). All this confirms the progressive increase in the marine level from the base of this sequence towards the top; the deposit environment evolves thus from continental to marine.

Only one sample was analyzed in the sequences Al7 and Al8 because of the lack of sample. It is about the sample at 4002 m which represents the top of the first sequence and the limit of sequence (SB) of the second (Figures 2 and 3). The organic matter contents and the petroleum potential, at that depth, are fair.

In this well Freedom 1, the rocks which can be considered as source rocks (TOC > 0.5 weight %) are indexed from the top of the TST of the sequence Al3 to the SB of Al8, except for three samples in the HST of Al3. However, because their petroleum potentials being poor, with an average lower than 2.5 mg HC/g TOC, these rocks are thus qualified as bad source rocks.

3.2 FREEDOM 2

Three stratigraphic sequences make the Albian interval in this well : Al5 from 2498 m to 2435 m, Al9 between 2435 m and 2408 m and Al10 from 2408 m to 2362 m [3]. The albian rocks in this well are characterized by good quantities of OM at the early maturity stage (Table 3).

The base of this well is consisted of the sediments of the TST (between 2498 m and 2481 m) and of the HST (from 2463 m to 2435 m) of the sequence Al5 [3]. The TST is characterized by a good quantity of OM early mature, with an average of TOC

which is approximately 1.63 weight % and Tmax of 435 °C (Figures 4 and 5). Moreover, the HI reveals values ranging between 201 and 293 mg HC/ g TOC and show OM contents from continental and marine origin. This OM of the type II/III testifies a marine deposit environment with continental influence which would correspond to a transitional environment, probably deltaic. The ascending evolution of the TOC and S2 in the TST (Table 3), would testify the good conditions of OM preservation, in phase with the rise of the marine level, which would support the deposit of an increasing quantity of OM.

This sequence Al5 is marked by a change in the type of organic matter from the TST to the HST, because the mixed OM of the type II/III giving way to the OM of the type II. This attest the increasing evolution of the marine level which, once the sea level is at its highest (maximum), supports the development of marine organisms. Indeed, the deposits of the HST (between 2463 m and 2435 m) of this sequence are characterized by marine OM (351 < HI < 413 mg HC/g TOC) in a good quantity (TOC average is about 1.92 weight %). This OM, at the early maturity stage (437 < Tmax < 441 °C), has a good petroleum potential because S2 is including between 5.41 and 10.83 mg HC/g rock. The high values of S2 and TOC (10.83 mg HC/g rock and 2.77 weight % respectively) at 2435 m, which is the top of this sequence, indicate the good conditions of OM preservation.

Thus, the argillaceous deposits and limestones located between 2481 m and 2435 m [3] constitute the hydrocarbon producing source rocks. They are source rocks producing of oil and gas in the TST and purely oil in the HST. The evolution of OM type, TOC, and S2 in this sequence suggests thus a change in deposit environment.

It would be about a transitional inner neritic environment for the TST evolving to a confined marine environment at the HST, where the continental influence is therefore null. Indeed, [3] indicated an inner neritic deposit environment at the sequence Al5.

Table 3. Rock-Eval pyrolysis results of Freedom 2

Age	Sequence stratigraphic [3]	System tract [3]	Depth (m)	S2	Tmax	HI	TOC
Albian	Al10	HST	2362	1.77	439	241	0.73
			2371	3.55	437	403	0.88
		TST	2381	4.41	438	369	1.2
			2399	7.11	436	446	1.59
	Al9	HST Top	2408	8.45	439	438	1.93
		TST	2417	6.75	438	494	1.37
			2426	6	439	340	1.76
	Al5	HST	2435	10.83	437	391	2.77
			2445	7.46	438	393	1.9
			2451	6.24	441	413	1.51
			2454	6.58	439	350	1.88
			2463	5.41	438	351	1.54
		TST	2481	6.13	435	293	2.09
			2498	2.32	435	201	1.16

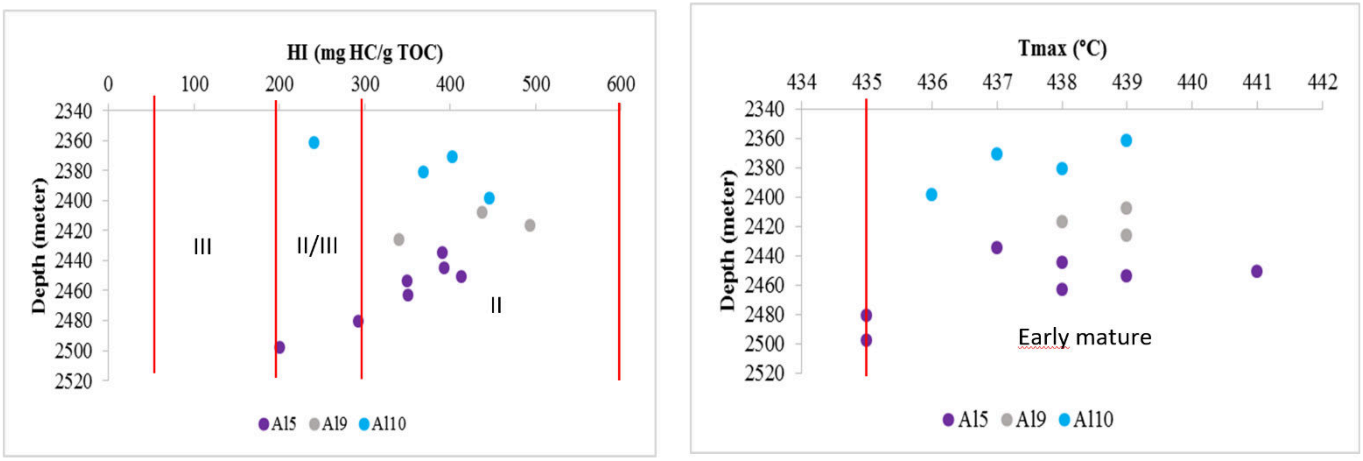

Fig. 4. Curve of evolution of the HI (a) and Tmax (b) according to the depth of Albian deposits in the well Freedom 1

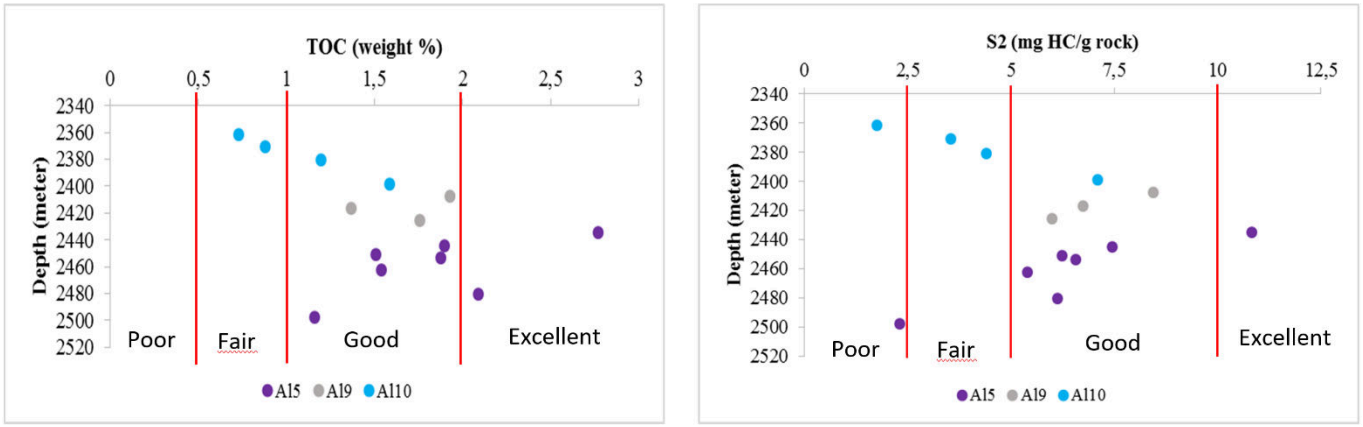

Fig. 5. Curve of evolution of TOC (a) and the S2 (b) according to the depth of Albian deposits in the well Freedom 1

OM in the sequence Al9 and at the base of Al10 (in the TST), are early mature (436 < Tmax < 439 C) and of the type II (HI evolving between 340 and 446 mg HC/g TOC). That would indicate the strong presence of marine water which brings marine organisms in the deposit environment.

The deposit environment goes from inner neritic to middle neritic in the sequence Al9 to outer neritic at the sequence Al10 [3]. According to these authors, the sequences Al9 and Al10 are made up of marls and claystones. These deposits ranging between 2426 m and 2408 m, in Al9; constitute, with those of the TST of the sequence Al10 (between 2399 m and 2381 m) an interval with a good TOC estimated at an average of 1.57 weight %.

The petroleum potential is also good with the S2 values which vary from 4.41 to 8.45 mg HC/g rock for an average of 6.54 mg HC/g rock (Figure 5). These marly and argillaceous deposits of the sequence Al9 and the TST of the sequence Al10 are thus a good source rocks producing liquid hydrocarbons (oil).

But, the HST deposits of Al10 (2371 m and 2362 m) are characterized by a fall of the OM quantity and petroleum potential, going respectively from 0.88 to 0.73 weight % and 3.55 to 1.77 mg HC/g rock. This decline of TOC and S2 values would be due to the progradation of the HST deposits related to the progressive decrease of the sea level which would have supported the gradual oxygenation of the deposit environment. The sea water level decrease allows an increasingly significant detrital contribution such as quartz in silty or sandy grain size. Consequently, the good conditions of OM preservation are degraded and manifested by a fall of the OM quantity and the petroleum potential. This gradual decrease of the sea level would be, also, responsible owing to the fact that the OM origin, in the HST, passes from type II to type II/III from 2371 m to 2362 m (Figure 4).

Apart from the sediments of 2498 m and 2362 m, the deposits of the Albian interval in this well are hydrocarbon producing source rocks mainly with oil. However, according to [3], a good source rock must have a TOC minimum ranging between 1.5

and 2 weight %. Thus, the significant source rocks are those ranging between 2481 m and 2399 m, except the rocks at 2417 m where the TOC is 1.37 weight % (Table3).

4 DISCUSSION

The sequence Al3 in the well Freedom 1 comprises two systems tracts, the TST (from 4132 m to 4050 m) and the HST between 4050 m and 4005 m [3]. Although the TOC contents and the OM type do not constitute a stratigraphic tool [8], they allow to distinguish the lowstand system tract (LST, between 4132 m and 4110 m) from the TST (between 4110 m and 4050 m) in this sequence. This remark would proceed of the evolution of the sea level and then would show the existence of a transgressive surface at 4110 m (Table 2). Indeed, in the TST defined by [3], OM is early mature and passes respectively from the type III, between 4132 m and 4110 m, to the type II/III between 4110 m to 4050 m except at 4104 m. A regression caused by the sea level decrease, between 4132 m and 4110 m, would have allowed a terrigenous sedimentary contribution thus containing the OM of the type III. Moreover, the TOC rate which is poor, between 4132 m and 4116 m, becomes fair between 4010 m and 4050 m.

The process in the beginning of the primary production of OM is the photosynthesis [10] which is the only way by which a new OM is synthesized on the earth [11]. And the primary producers able to carry out the reaction of photosynthesis are the autotrophic organisms, corresponding in oceanic area to the planktonic micro-organisms which are the diatoms, dinoflagellates, coccolithophorids and cyanobacteria [10]. The TST should thus have OM contents of the type II and/or II/III like the albian sequences of Freedom 2. According to [11], type II/III describes a transitional composition between the types II and III and represent generally a mixture of marine and terrigenous OM deposited in a paralic environment. [12], in his provisional report for Ifremer, stipulates that the paralic systems concern estuaries, deltas, marine lagoons and marine marshes. However, [3] have interpreted the Albian deposit of this study as inner to outer neritic environment. Thus, the environment with OM of the type II/III according to the Rock-Eval analysis in this study would indicate a deltaic deposition environment, like the interval between 4110 m and 4014 m, in the sequence Al3 of Freedom 1. The presence of continental OM at 4104 m, 4038 m and 4032 m in this sequence would be due to the influence of continental inputs in the deposition environment. The other hypothesis of explication of this presence at 4104 m especially, comes from the fact that, during the rise of marine waters, the action of the waves causes a remobilization of the substratum [13]. Subsequent deposition of these reworked sediments containing, probably OM of the type III in the transgressive interval, would then justify this presence in the TST this sequence. Thus, the sequence Al3 would consist of a lowstand system tract (LST) between 4132 m and 4110 m, a TST from 4110 m to 4050 m and HST between 4050 m and 4005 m.

However, the Gamma Ray (GR) evolution coupled with the biostratigraphic data used by [3] for the determination of the sequences and their systems tracts is opposed to the systems tracts identification in the sequence Al3 of Freedom 1 of this study. Indeed, the GR evolution from 4132 m to 4100 shows high values [3] which would rather cause by a rise of sea level. And the significant positive peak of the GR at 4100 m [3] could be the print of a maximum flooding surface (MFS). But, the acme zone of planktonic foraminifers at 4050 m [3] was more significant for the identification of the SIM of the Al3 sequence. Nevertheless, the evolution of the hydrogen index evokes other assumptions of explanation of these high Gamma Ray values at the base of the sequence Al3. A considerable flow of detrital sediments rich in radioactive elements (K, Th, U) could justify these strong measurements of the Gamma Ray. In fact, illite, potassium feldspars and micas are potassium-bearing minerals [14, 15] and zircon can be a mineral carrying thorium and uranium [15]. Thus, the decline in Gamma Ray values beyond 4100 m [3] would be explained by the decrease in continental inputs caused by the rise of marine waters in the deposit environment.

In addition, the biostratigraphic data of this well indicate the presence of palynomorphs (spores and pollens) and a quasi-absence of foraminifers from 4132 m to 4100 m. Only rare planktonic foraminifera represented by the species Hedbergella spp. appear at 4104 m.

The collection of these informations suggests that the deposit environment of this section between 4132 m and 4100 m would be in a coastal environment. All these data corroborate therefore the existence of the lowstand system tract in the sequence Al3 of Freedom 1.

Finally, this sequence Al3 in Freedom 1 would be a complete sequence with LST from 4132 m to 4100 m, TST from 4100 m to 4050 m and HST from 4050 m to 4005 m.

5 CONCLUSION

This methodological approach allows easily to understand the organic facies variations in the sequences, particularly in the control of organic matter accumulation and quality. In this study, the OM are early mature and the variations in their origins testify the changes in the deposit environments in connection with the marine fluctuations.

The passage of the OM from type III to type II/III in the transgressive system tract already defined ahead in the sequence Al3 of the well Freedom 1, permit to distinguish the lowstand system tract from the transgressive system tract. The source rocks in this well are qualified as bad source rocks because of the poor petroleum potential. In the well Freedom 2, the OM evolution from the type II/III to the type II shows a strong marine presence having supported good conditions of OM preservation. The good quantities of OM and petroleum potential permit to indicate the albian rocks of this well as good source rocks producing mainly oil hydrocarbon.

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