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Terrestrial influence on the late Cretaceous Tethyan-Atlantic Epeiric Sea in the Yola Basin, Northern Benue Trough, Nigeria

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ABSTRACT

A multi-proxy investigation was carried out on three outcrop sections from the Upper Cretaceous Numanha Formation extended in the Yola Basin of the Northern Benue Trough, Nigeria. The Numanha Formation is a predominantly shale sequence that preserves the Turonian–Coniacian depositional history of the Atlantic and shallow southern Tethyan seaway. The investigation included palynofacies characterization of the sedimentary organic matter content of 61 samples collected from three sections, NL10, NL8, and NL4, in addition to analyses for the total organic carbon (TOC) and carbon:nitrogen (C/N) ratios in 44 samples from all of the three studied sections. Palynofacies data confirms an overall marginal marine (estuarine) depositional setting for the Numanha Formation which was strongly impacted by terrestrial and freshwater sources. This is based on the following observations: 1) near-constant presence of marine dinoflagellate cysts and/or benthic planispiral microforaminiferal inner linings, 2) strong terrestrial contribution of transported vascular plant fragments such as opaque, structured, and degraded phytoclasts with fluxes of cuticles at certain intervals, 3) near-constant presence of the freshwater alga *Pediastrum* which was also recorded in high proportions at certain intervals. TOC content for the majority of the analyzed samples was generally low (<1%) indicating poor organic matter preservation potential which was probably due to high energy and well-oxygenated conditions. C/N ratios were mostly below 20 for the analyzed samples from all sections confirming the inferred marine depositional settings. There were, however, two exceptionally high C/N anomalies that were seen in all of the three studied sections, but were especially pronounced in the NL4 section, which were also coupled with elevated TOC content. These are herein interpreted to represent periods of increased terrestrial input, probably as a result of high continental runoff, associated with selective diagenetic consumption of nitrogen by microbial degradation.

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1. Introduction

The Benue Trough is the largest inland sedimentary basin in Nigeria. It is an elongated NE-SW trending rift basin about 1,000 km long and 150 km wide. It is bounded in its southern limit by the Niger Delta, while in its northern extreme it is bounded by the Bornu Basin (Fig. 1). The trough is arbitrarily subdivided into three portions comprising the Southern (Lower) Benue Trough with depocenters around Nkalagu and

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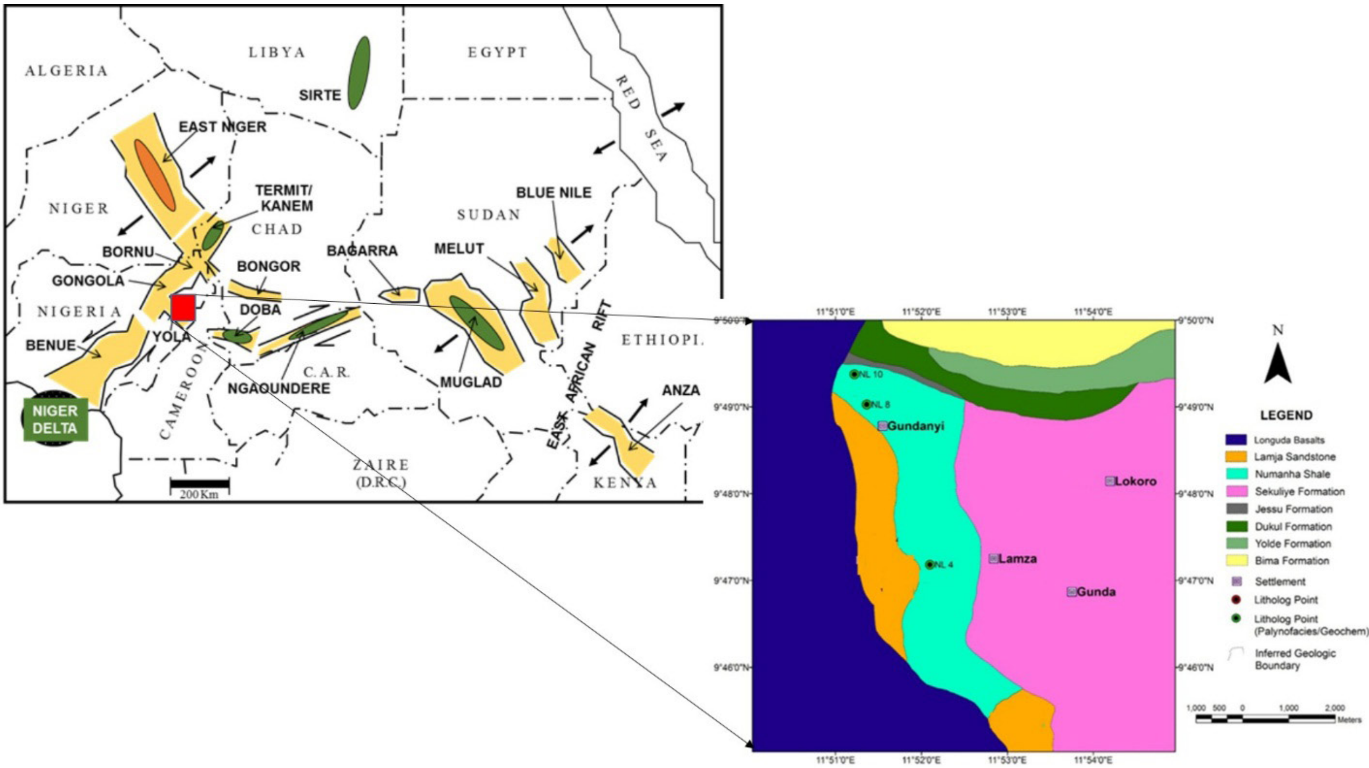

Figure 1. (A) Regional tectonic map of western and central African rifted basins showing the relationship of the Muglad, Doba, and East Niger Basins to the Chad Basin/Benue Trough. Location of regional shear zones (marked with half-arrow) and major zones extension (complete arrow) are shown. Major oil discovery . Major oil and gas shows (modified from Schull, 1988). (B) Geological map of the study area showing location of studied sections.

Abakaliki, Central (Middle) Benue Trough with depocenters around Makurdi, Lafia, and Wukari while the Northern (Upper) Benue Trough which is further subdivided into the Gongola Basin and Yola Basin with depocenters at Pindiga, Nafada, Ashaka and Tula, Guyuk, Bambam respectively (Obaje et al., 1999). The Yola Basin is the E-W trending part of the Northern Benue Trough which is the northernmost part of the Benue Trough containing about 6,000 m of continental to marine sediments ranging in age from Aptian to Santonian (Fig. 2).

Nigeria's current national petroleum reserve is put at 37.2 billion barrels of oil and 170 trillion standard cubic feet of gas derives solely from the Niger Delta (deep-water and ultra-deep-water offshore). Exploration efforts by oil companies in the Nigerian frontier inland basins have been minimal due probably to the high risk involved. This high risk on investment is due largely to poor knowledge of the geology and petroleum systems of the area. However, commercial volumes of hydrocarbons have been discovered in the contiguous Chad and Sudan inland basins which are all part of the series of Cretaceous rift basins in Central and West Africa whose origin is related to the opening of the south Atlantic (Fig. 1). In SW Chad, development of the Doba discovery gave estimated reserves of about 1 billion barrels of oil by Exxon Mobil Company. Giant oil fields have been discovered in the Muglad Basin in Sudan. The major source and reservoir rocks in the Muglad basin occur in continental Aptian–Cenomanian deposits which are similar to and can be correlated with the Bima Sandstone of the Northern Benue Trough, Nigeria. In the Niger Republic, oil and gas shows have been encountered in the Mesozoic-Cenozoic sequences in the East Niger graben, which is structurally related to the Benue-Chad-Sudan-Libyan Rift Complexes.

Three exploratory oil wells have been drilled in the contiguous Gongola Basin of the Northern Benue Trough, with none in the adjacent Yola Basin which has similar sedimentary sequences and tectonic histories. Only Kolmani-River 1 well was found to contain 33 billion standard cubic feet of gas with little oil (Shell Nigeria Exploration and production Com., 1999). These wells were all drilled in the contiguous Gongola Basin of the Northern Benue Trough, none has been drilled in the adjacent Yola Basin with similar sedimentary sequences and tectonic histories. The

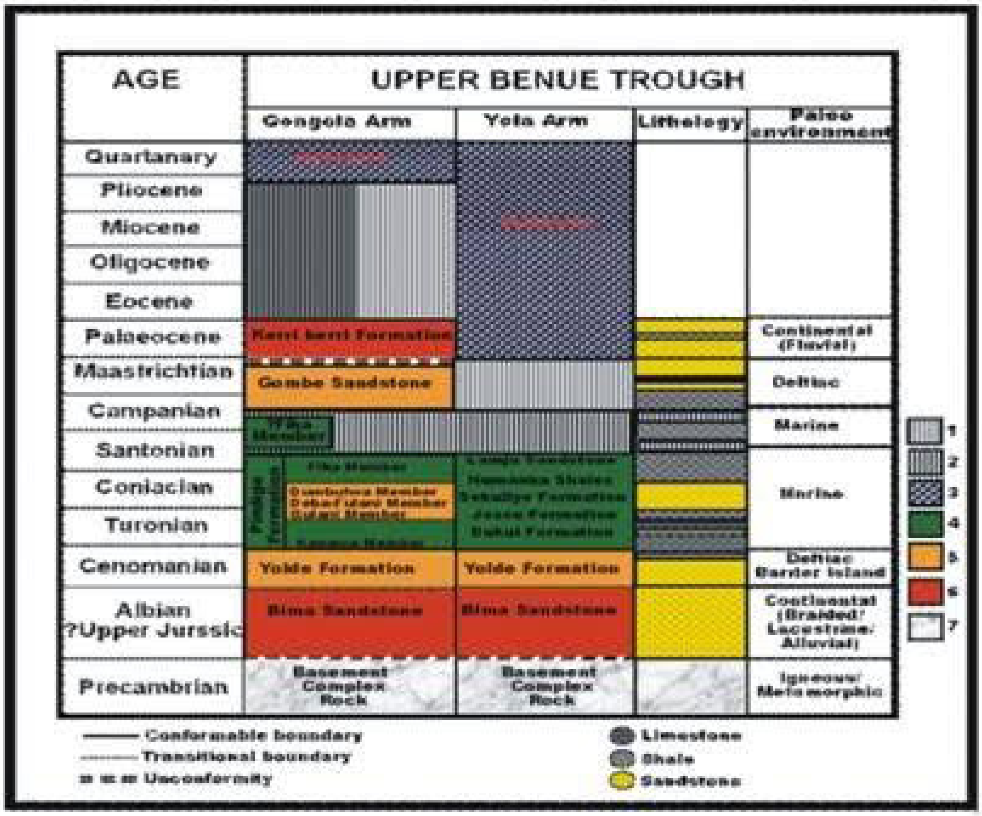

Figure 2. Stratigraphy of the Northern Benue Trough (Obaje et al., 1999).

lack of interest of the oil companies in the Yola Basin is mainly due to poor knowledge of the geology and petroleum systems elements of the area. This article is part of the efforts at bringing the potential of the basin to the public domain using integrated microscopy and geochemical techniques. This approach has been underutilized by previous workers from the basin. The call to sustain hydrocarbon exploration to meet up with global and domestic energy needs of the country for its economic development provoked this effort.

2. Materials and Methods

Sixty-one and forty-four outcrop samples were processed for palynofacies and geochemistry respectively from three sections of the Numanha Formation. The palynological processing performed in the Palynological Laboratory at the Missouri University of Science and Technology Rolla, USA involved the digestion of samples in hydrochloric (HCl) and hydrofluoric (HF) acids to remove carbonates, silicates, and fluorides resulting from HF acid treatment from the sediments (Traverse, 2007). Preparation of kerogen slides for palynofacies analysis followed the acid digestion. 300 particulate organic matter particles were point counted per kerogen slide and used for palynofacies analysis.

Total carbon and total nitrogen, TOC analyses were carried out at the Stable Isotope Laboratory, University of Florida. Samples were loaded into tin capsules and placed in a 50-position automated Zero Blank sample carousel on a Carlo Erba NA1500 CNHS elemental analyzer. After flash combustion in a quartz column containing chromium oxide and silvered cobaltous/cobaltic oxide at 1000°C in an oxygen-rich atmosphere, the sample gas is transported in a He carrier stream and passes through a hot reduction column (650°C) consisting of reduced elemental copper to remove oxygen. The effluent stream then passes through a chemical (magnesium perchlorate) trap to remove water. The stream then passes through a 1-m gas chromatographic column at 120°C that separates the N_2 and CO_2 gases. Finally, the gases pass through a thermal conductivity detector that measures the size of the pulses of N_2 and CO_2.

Total inorganic carbon was measured coulometrically using a UIC (Coulometrics) 5,011 CO_2 coulometer coupled with an AutoMate automated carbonate preparation device (AutoMateFX.com). Approximately 15 mg of the sample is weighed into septum top tubes and placed into the AutoMate carousel. A double needle assembly is used to purge the sample vial of atmospheric gas using CO_2-free nitrogen carrier gas. Acid is then injected into the sample vial and evolved CO is carried through a silver nitrate scrubber to the coulometer where total C is measured.

3. Results

3.1. Field observations

Three sections of the Numanha Formation were encountered comprising Tsintsire 1 (NL4), Gundenyi 1 (NL8), and Kurnyi (NL10) (Table 1 and Fig. 1).

Table 1. Location of sections, their formations, and coordinates.

S/No	Section	Section code	Formation	Coordinates
i.	Tsintsire 1	NL4	Numanha	N09° 50″, E011° 51″
vi.	Gundenyi 1	NL8	Numanha	N09° 53″, E011° 50″
viii.	Kurnyi	NL10	Numanha	N09° 54″, E011° 49″

3.2. Lithostratigraphic descriptions

3.2.1. Tsintsire 1 section

The Tsintsire1 section is an east-west horizontally disposed beds consisting of intercalations of shale and calcareous mudstones and limestone (Fig. 3). The shale beds range in thickness from 2–12 m with an upward thickening pattern. Five calcareous mudstone horizons with thicknesses ranging from 0.5–0.7 m thick. The shales are dark and fissile but the lower beds are more indurated. The shales and the associated mudstone horizons have sharp boundaries. The total thickness of the section is 37.9 m thick.

3.2.2. Gundenyi 1

The Gundenyi 1 section is an east-west disposed beds consisting of intercalations of shales, calcareous mudstone, and fossiliferous limestones (Fig. 4). The shales are dark and fissile with thicknesses ranging between 2 and 11 m. The mudstone and limestone horizons have sharp contact with the shales. The mudstones and the limestones are also dark grey except for the two upper limestone beds that are compact with pelecepod shells. The total thickness of the section is

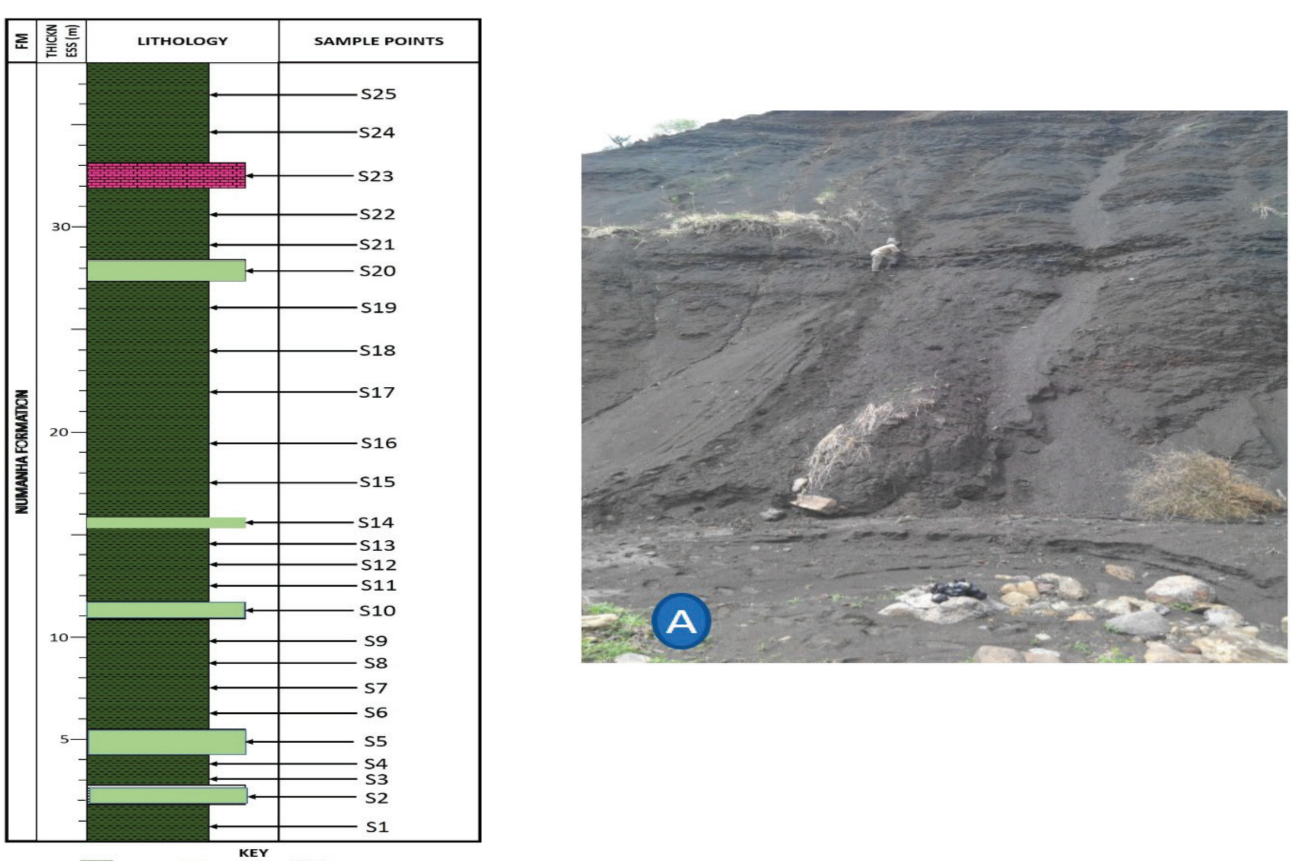

Figure 3. Lithologic section of Tsintsire (NL4) and the view photo of the section.

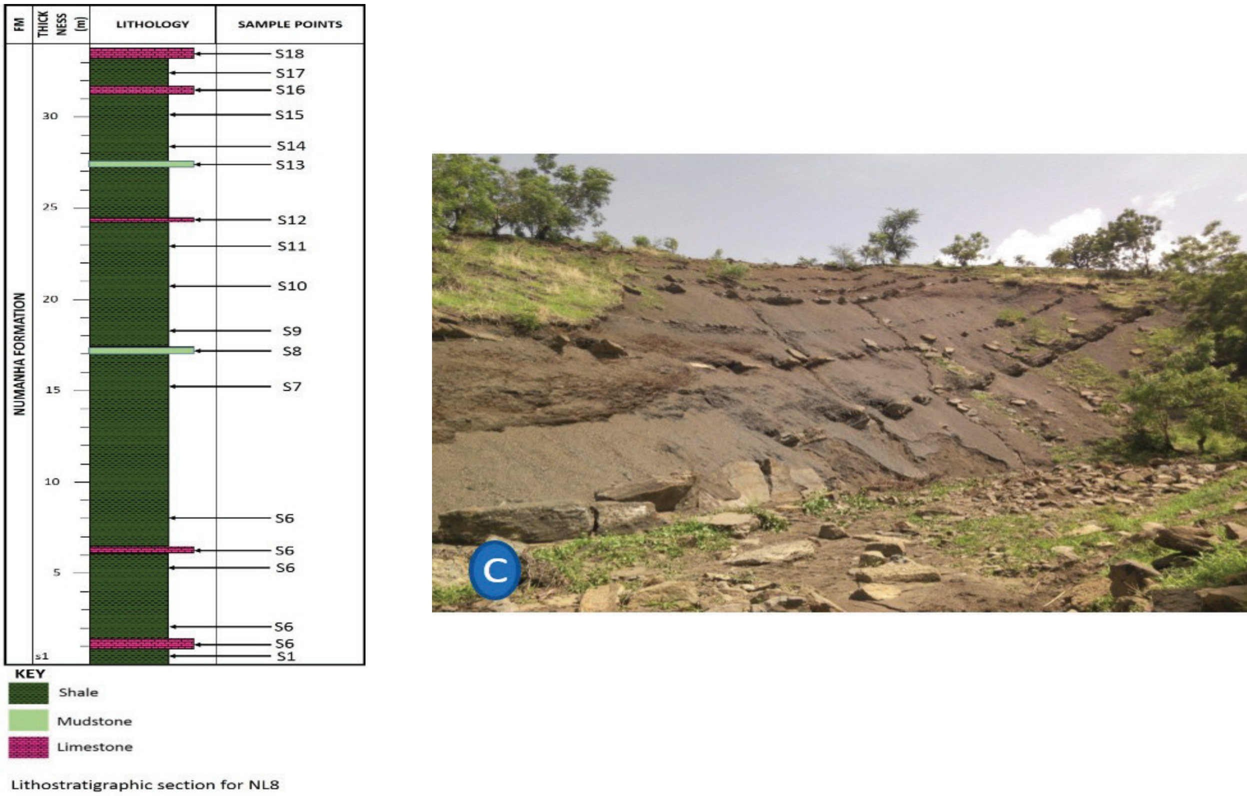

Figure 4. Lithologic section of Gundenyi (NL8) and view photo of the section.

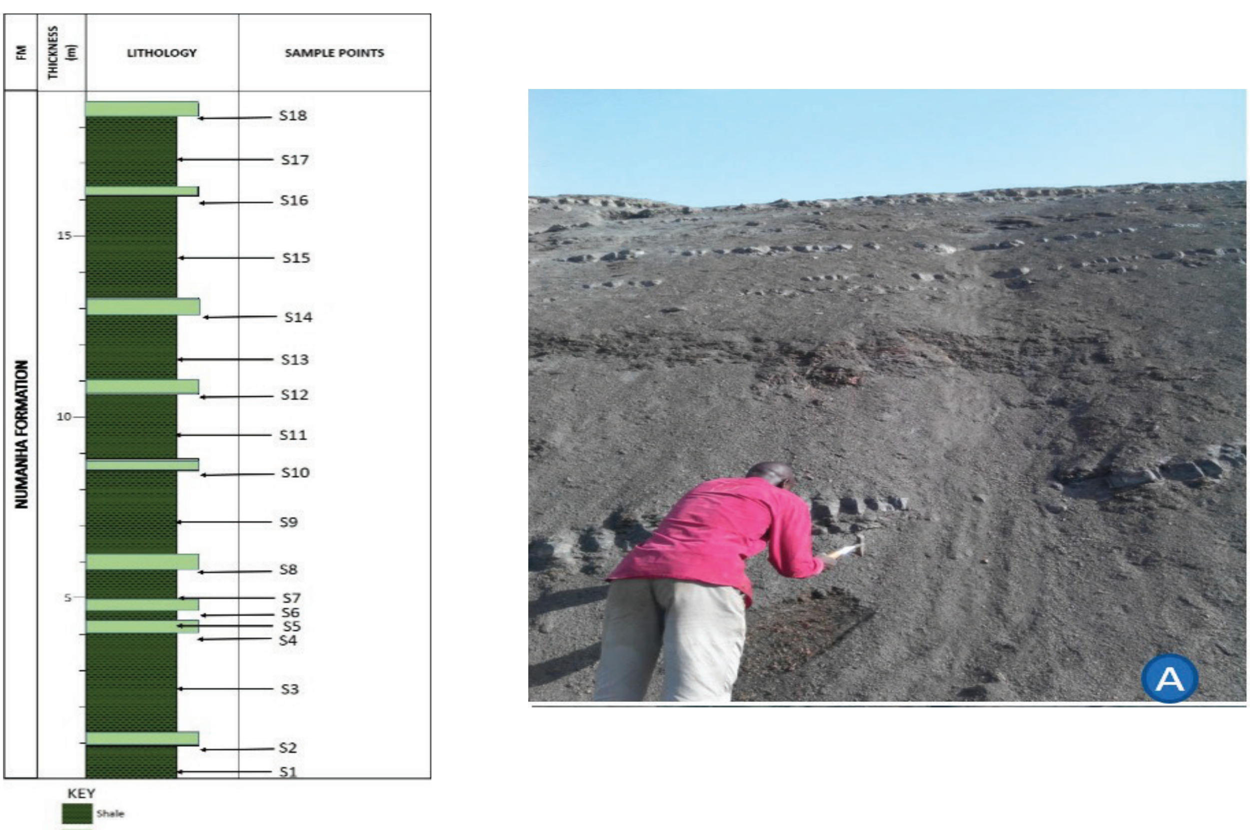

Figure 5. Lithologic section of Kurnyi (NL10) and the view photo.

33.76 m. There is no regular stacking pattern of the lithologies in this section.

3.2.3. Kurnyi section

The Kurnyi section is disposed of east-west extending for about 200 m and the vertical thickness is 18.22 m (Fig. 5). It is composed of interbeds of dark fissile shales and dark mudstones. The thicknesses of the shale beds range from 1 to 3 m while the mudstones range from 8 to 25 cm. The mudstones have sharp boundaries with the shale beds. The shale beds are gypsiferous.

3.3. Palynofacies

Sixty-one samples of shales, mudstones, and limestones from three sections of the Numanha Formation were analyzed. Palynofacies components are classified as phytoclast, palynomorphs, and amorphous organic matter (AOM) for the quantitative analysis. The qualitative analysis is based on the degree of degradation/preservation and optical properties viz., coloration, opaques, translucent, etc. Quantitative data are plotted in percentage logs using the program Tilia Gview 2.0.2 (Grim, 1992) and on Tyson's amorphous-phytoclasts-palynomorph (APP) (AOM–Phytoclast–Palynomorph) ternary diagram to derive the palynofacies and also to categorize the kerogen type.

3.3.1. Tsintsire section (NL4)

The Tsintsire section has 25 samples of shales, limestones, and calcareous mudstones that have been analyzed. The relative percentages of the particulate organic matter are presented in Table 2. The opaque phytoclast dominates generally. Dinoflagellate cysts, foraminiferal lining, and freshwater algae (*pediastrum)* are abundant. Plates 1A and B, 2 shows a photomicrograph of palynofacies. The relative distribution diagram for the palynofacies is shown in Figure 6.

3.3.2. Gundenyi 1 section (NL8)

The Gundenyi 1 section is composed of shales, calcareous mudstones, and limestones. 18 samples were analyzed. The result of the relative percentage of palynofacies groups and the percentage distribution

Table 2. Relative percentage of palynofacies for Tsintsire (NL4) section.

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL4s1	11.00	8.67	31.00	9.00	38.00	2.33	100.00
NL4s2	1.00	1.33	39.00	12.33	41.33	5.00	100.00
NL4s3	0.00	6.67	53.33	7.00	30.00	3.00	100.00
NL4s4	0.67	19.33	48.00	6.00	25.33	0.67	100.00
NL4s5	0.33	27.67	40.00	5.33	26.33	0.33	100.00
NL4s6	35.67	8.67	21.67	13.00	18.67	2.33	100.00
NL4s7	19.67	2.00	23.33	16.33	37.33	1.33	100.00
NL4s9	7.33	22.67	9.67	22.00	26.33	12.00	100.00
NL4s10	10.00	20.33	10.33	17.33	38.67	3.33	100.00
NL4s11	11.00	37.00	15.33	11.00	22.33	3.33	100.00
NL4s12	29.00	28.00	10.00	10.33	20.00	2.67	100.00
NL4s13	8.33	45.00	5.00	5.67	35.67	0.33	100.00
NL4s14	16.00	34.33	5.00	18.33	25.00	1.33	100.00
NL4s15	11.67	12.33	19.00	5.67	52.67	0.00	101.33
NL4s17	25.67	30.67	10.00	20.67	12.33	0.67	100.00
NL4s19	24.00	14.67	10.67	12.00	36.00	2.67	100.00
NL4s20	13.33	40.67	4.33	18.67	23.00	0.00	100.00
NL4s21	5.00	5.67	31.67	4.67	52.33	0.67	100.00
NL4s22	2.67	9.33	19.33	2.00	66.00	0.67	100.00
NL4s23	2.33	16.00	7.33	40.33	33.67	0.33	100.00
NL4s24	12.67	12.00	17.33	12.33	44.67	1.00	100.00

NB: Pal = Palynomorphs, Struc. Phyto = Structured phytoclast, Degr Phyt = Degraded phytoclast, Opaq. Phyt = Opaque Phytoclast, AOM = Amorphous organic matter.

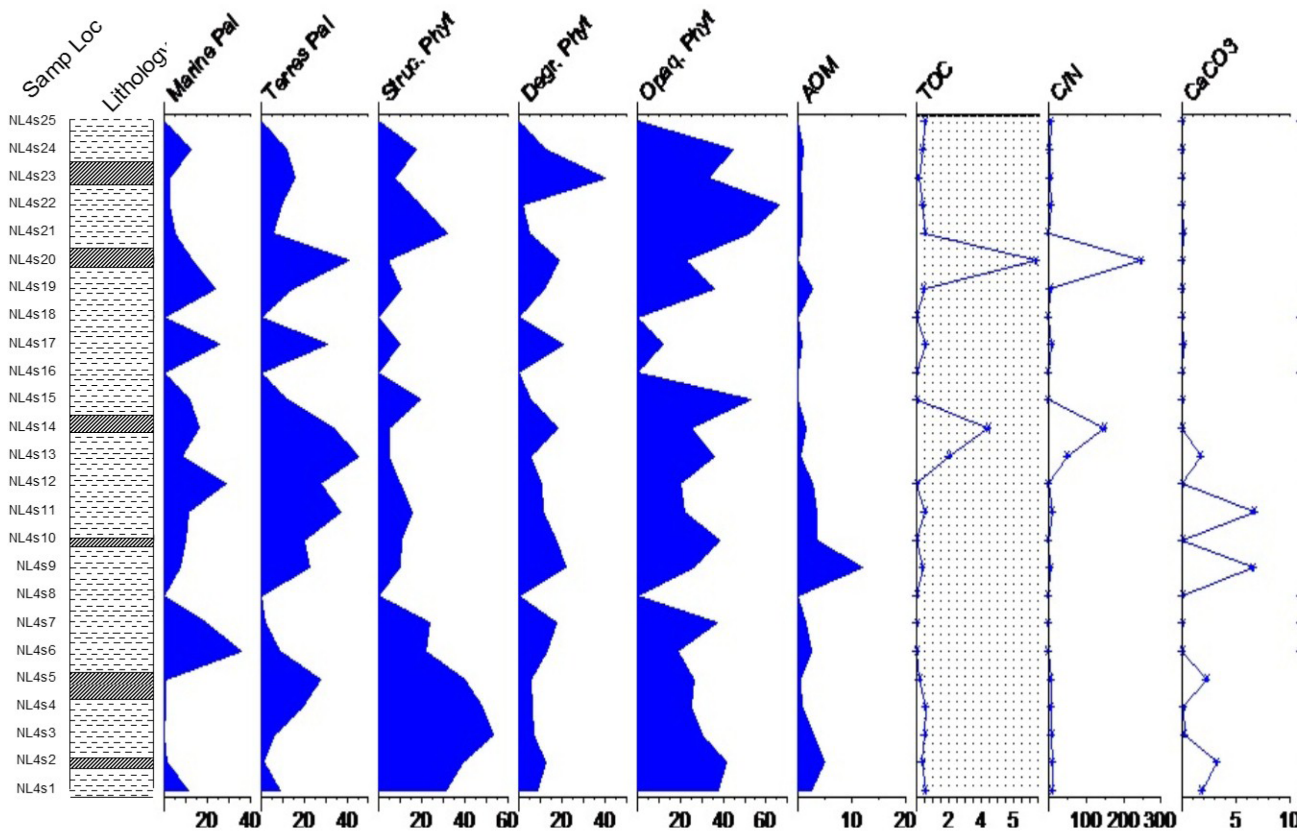

Figure 6. Percentage distribution of particulate organic matter for Tsintsire (NL4) section.

diagram of particulate organic matter is shown in Table 3 and Figure 7, respectively. The photomicrograph of palynofacies is on Plates 1C and B, 2. The structured and opaque phytoclast domination may have dilution effects on the other palynofacies groups. The organic matter however indicated the presence of both terrestrial and marine sourced characteristics based on the carbon:nitrogen (C/N) ratio. The abundance of dinoflagellate cysts and foraminiferal test linings depicts a marine environment.

3.3.3. Kurnyi section (NL10)

Eighteen samples of shales and mudstones were analyzed in this section. Table 4 shows the relative percentage of particulate organic matter. Plates 1E and F, 2 is the photomicrograph of the particles snapped under transmitted white light. The relative abundance of terrestrial palynomorphs in samples (NL10s8 and NL10s9) is significant. The opaque phytoclast dominates in all the samples throughout the section. This may be due to the long-distance transport of the particles. AOM whose percentage composition reflects the organic matter preservation potential of the environment of deposition is significantly present in the stratigraphic section. It, therefore, depicts a more distal environment compared to the other sections of the Numanha Shale studied. The consistent amount of total organic carbon (TOC) and the phytoplankton/bacteria source inputs of the organic matter based on C/N ratio supports the position of this section to be more distal than the others. The relative distribution diagram for the palynofacies is shown in Figure 8.

3.4. Geochemical analysis

Forty-four samples of shales, limestones, and mudstones from three sections of the Numanha Formation were analyzed for TOC and C/N ratio. Geochemical and palynofacies data have been found to be useful in the interpretation of paleoenvironments and the characterization of organic matter and its sources (Tyson, 1995). In this study, TOC, elemental C/N ratios were analyzed.

3.4.1. (TOC) and (C/N) ratio for Tsintsire section (NL4*)*

Seventeen samples were analyzed for TOC, carbon, and nitrogen. Values for TOC range from 0.12% to 7.40 % with a mean value of 1.16 %. The range for the C/N is between 0.02 and 246.67 (Table 5 and Fig. 9).

Table 3. Relative percentage of palynofacies for Gundenyi 1 (NL8) section.

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL8s1	5.67	1.67	19.00	5.33	65.33	3.00	100.00
NL8s3	22.00	5.67	55.33	6.00	11.00	0.00	100.00
NL8s4	5.00	2.33	48.67	17.33	25.67	11.00	110.00
NL8s6	6.33	8.00	60.67	3.33	21.00	0.67	100.00
NL8s7	5.00	4.00	55.33	3.67	31.67	0.33	100.00
NL8s8	16.33	5.67	44.00	5.67	27.67	0.67	100.00
NL8s9	7.67	6.33	54.33	2.00	25.33	4.33	100.00
NL8s10	2.67	5.00	64.00	4.33	22.33	1.67	100.00
NL8s11	5.00	2.33	51.00	5.67	34.67	1.33	100.00
NL8s12	1.67	1.33	61.33	2.67	32.00	1.00	100.00
NL8s13	13.00	2.33	54.00	0.67	29.33	0.67	100.00
NL8s14	5.00	3.33	43.67	6.33	40.33	1.33	100.00
NL8s16	0.67	0.33	20.00	34.67	43.33	1.00	100.00
NL8s17	0.33	1.67	34.00	6.67	57.00	0.33	100.00
NL8s18	0.67	1.33	12.33	61.00	24.67	0.00	100.00

NB: Pal = Palynomorphs, Struc. Phyto = Structured phytoclast, Degr Phyt = Degraded phytoclast, Opaq. Phyt = Opaque Phytoclast, AOM = Amorphous organic matter.

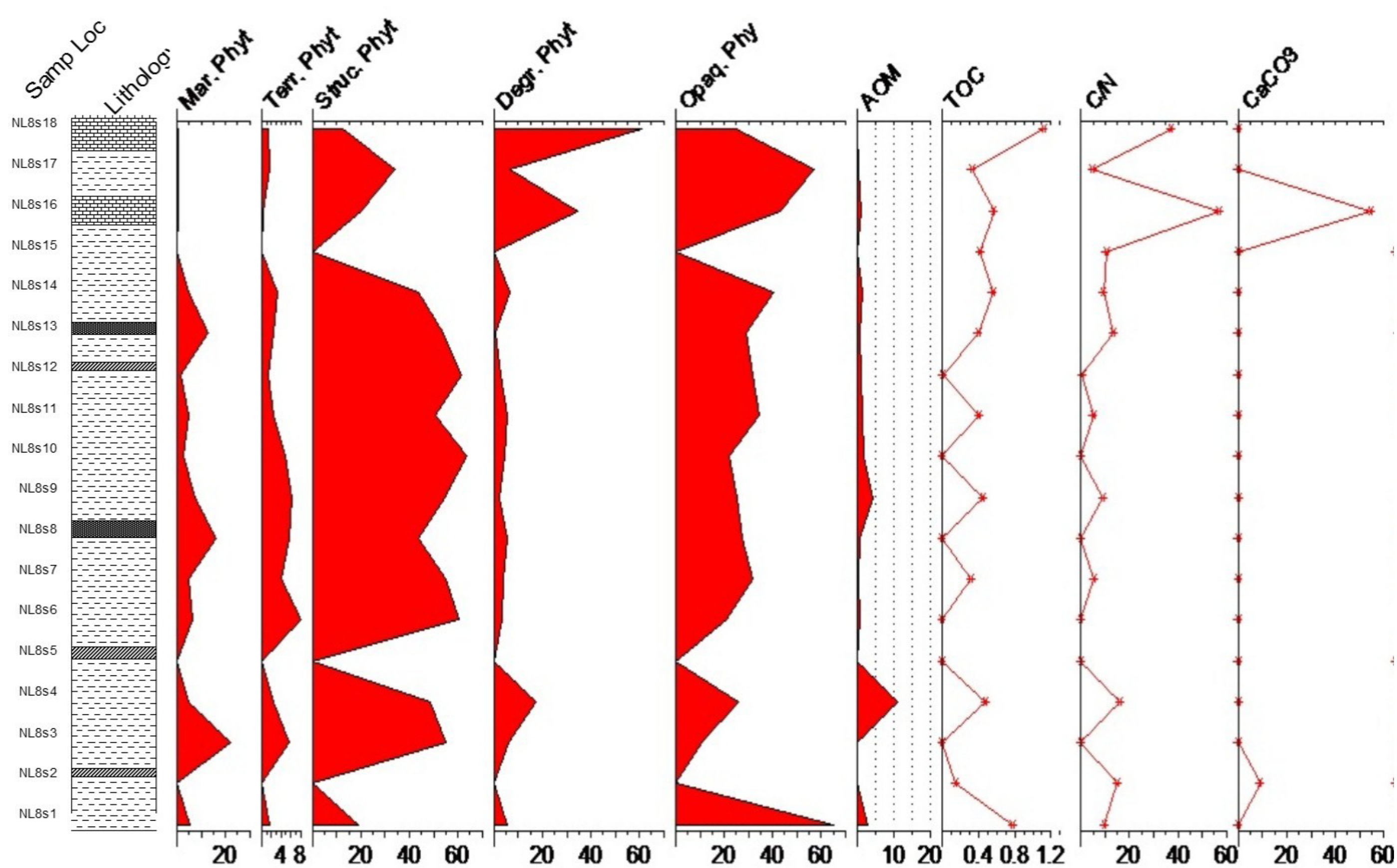

Figure 7. Percentage distribution of particulate organic matter in NL8 section.

Table 4. Relative percentage of palynofacies for Kurnyi (NL10) section.

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL10s1	19.67	29.67	22.00	6.00	22.33	0.33	100.00
NL10s2	11.00	14.33	28.33	16.67	24.33	5.33	100.00
NL10s3	5.33	19.33	20.00	18.33	31.33	5.67	100.00
NL10s4	13.33	17.33	13.00	5.67	45.00	5.67	100.00
NL10s5	28.33	14.33	19.00	9.00	25.33	4.00	100.00
NL10s6	21.33	24.00	12.67	9.67	28.33	4.00	100.00
Nl10s7	11.33	17.67	19.33	7.33	42.00	2.33	100.00
NL10s8	6.94	52.78	1.39	5.56	29.17	4.17	100.00
NL10s9	19.67	37.67	20.67	7.67	10.00	4.33	100.00
NL10s10	3.33	42.00	1.67	19.33	30.00	3.67	100.00
NL10s11	8.00	31.33	11.00	25.33	19.67	4.67	100.00
NL10s12	8.00	19.00	6.67	20.33	43.67	2.33	100.00
NL10s13	24.33	12.00	17.67	13.33	27.33	5.33	100.00
NL10s14	6.33	17.00	6.00	36.67	30.67	3.33	100.00
NL10s15	30.33	12.67	6.33	18.33	24.33	8.00	100.00
NL10s16	7.00	13.33	2.33	41.33	30.33	5.67	100.00
Nl10s17	1.00	7.00	5.67	33.00	52.00	1.33	100.00
NL10s18	2.67	6.00	5.00	45.67	38.33	2.33	100.00

NB: Pal = palynomorphs, Struc. Phyto = Structured phytoclast, Degr Phyt = Degraded phytoclast, Opaq. Phyt = Opaque Phytoclast, AOM = Amorphous organic matter.

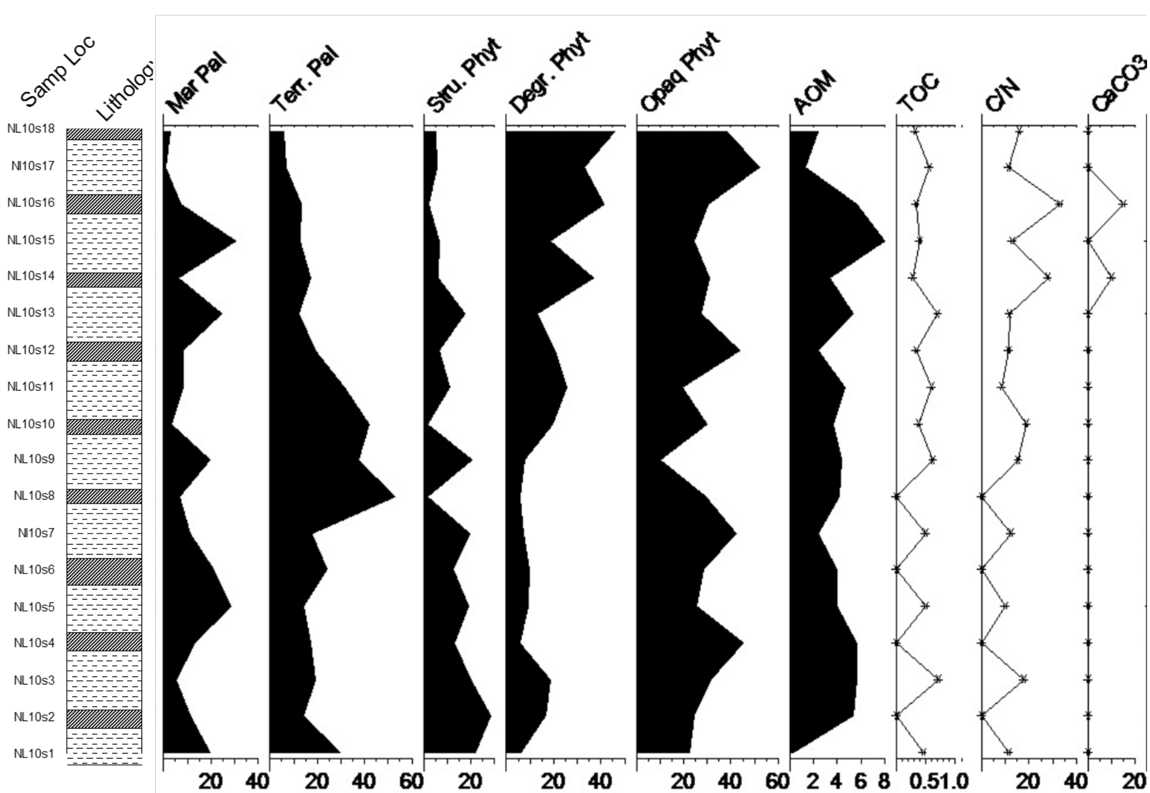

Figure 8. Percentage distribution of particulate organic matter in Kurnyi (NL10) section.

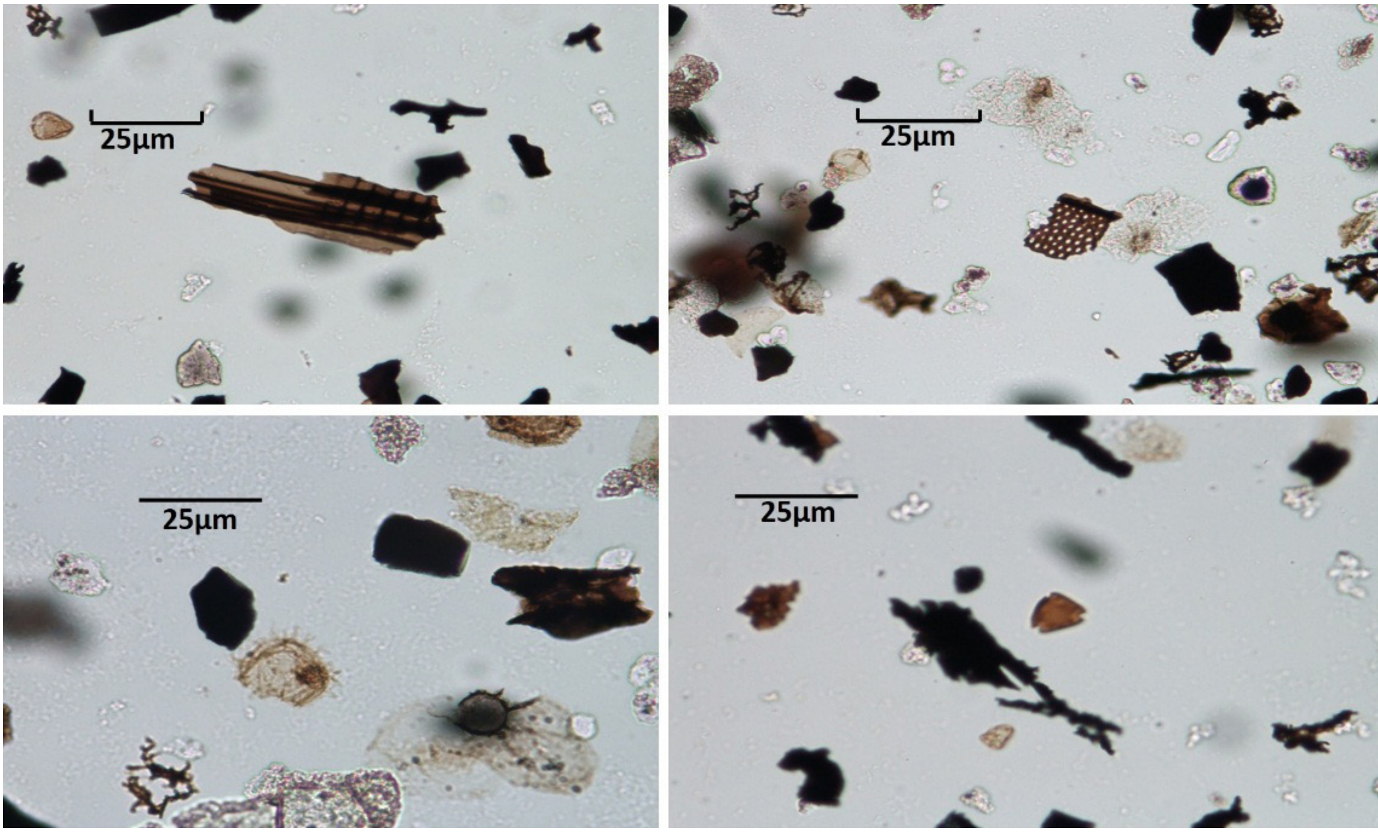

Plate 1. Representative photomicrographs of palynofacies from the Numanha formation.

3.4.2. (TOC) and (C/N) ratio for Gundenyi 1 section (NL8)

Thirteen samples were analyzed for TOC and C/N ratio from Gundenyi 1 section. The values obtained for TOC range from 0.01 to 1.12 wt. % and for the C/N ratio, it ranges from 0.02 to 246.67 (Table 6 and Fig. 10). The TOC is poor to fair except for samples NL8s1, NL8s14, NL8s16, and NL8s18 that have values higher than the minimum required value to generate hydrocarbon by Tissot and Welte (1984).

3.4.3. (TOC) and (C/N) ratio for Kurnyi section (NL10)

Fourteen samples from this section were analyzed. The TOC values for the samples range from 0.28 to 0.71 wt. % with a mean value of 0.47% (Table 7). The low TOC values are from the upper part of the section which corresponds with a high amount of phytoclast (Fig. 11).

4. Discussion

4.1. Lithostratigraphy

The Numanha Shales corresponds with the Late Turonian to Coniacian transgression succinctly discussed by Zaborski (2000). The formation represents open and more restricted marine conditions with alternations of shales and limestones dominantly. Suggestions for the cause of the carbonate/siliciclastic alternations have included water depth and the degree of dilution of carbonates by terrestrial materials due to changes in sea level and climate-induced episodes of increased freshwater run-off from the land. The supply of carbonate mud as zooplankton fecal pellets relative to clay has also been suggested as a cause for marl-shale alternations with diagenetic causes for the limestone, Studying the Lias of the Paris Basin recognized units of 0.1 to 0.4 Ma comparable to Milankovitch cycles which were thus of possible climatic origin. These were deposited in a storm-dominated, shallow epicontinental sea where increasing water depth caused fewer episodic injections of surficial oxygenated water below the storm wave base, thereby increasing the preservation of organic matter with thick shales as obtained in the Numanha Shale.

4.2. Palynofacies and paleoenvironment

The Phytoclast–Palynomorph: AOM ternary plot of Tyson (1995) placed the samples analyzed in four fields representing highly oxic-distal shelf environments

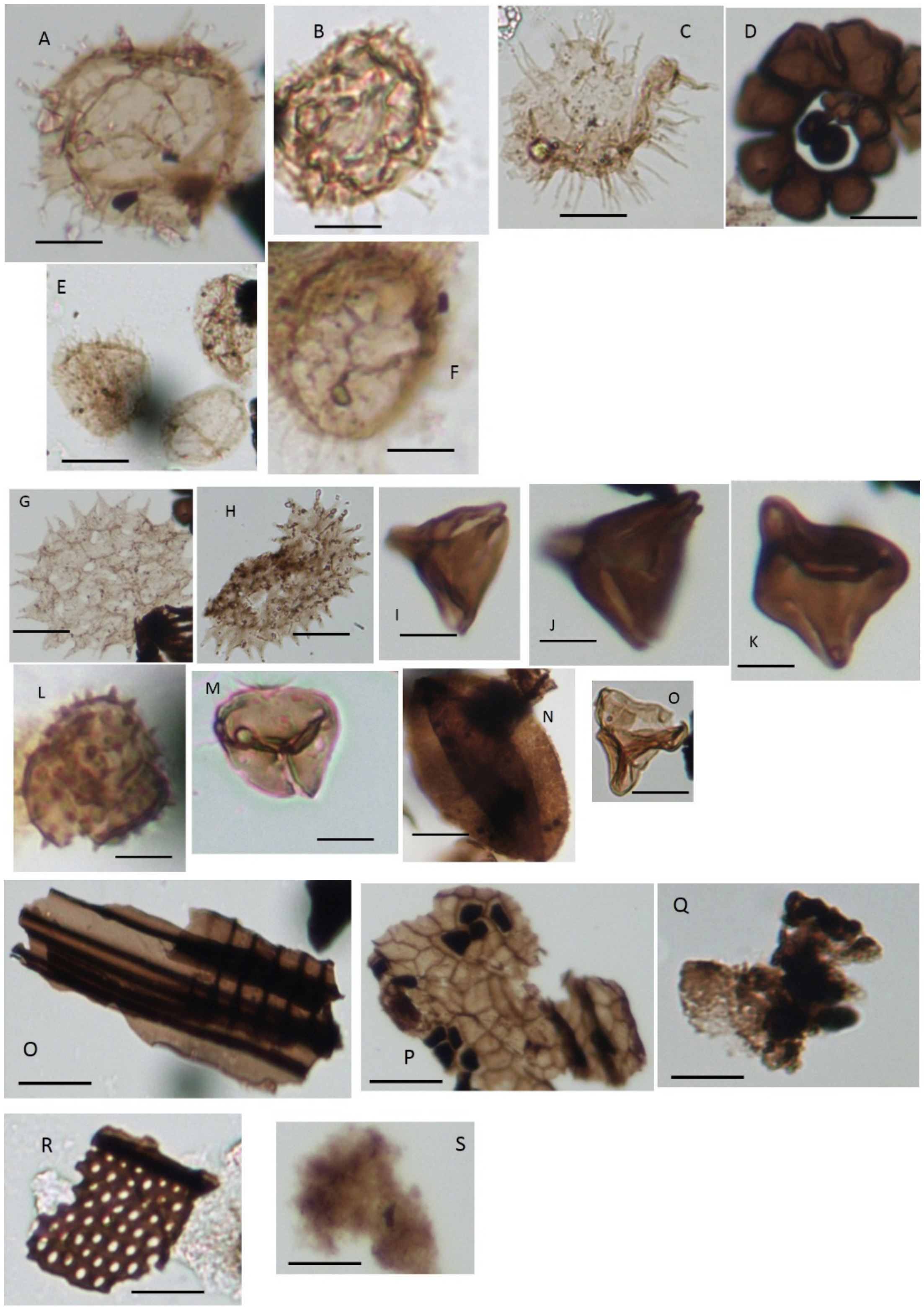

Plate 2. Representative photomicrographs of palynofacies components from the Numanha Formation: *A. Florentina berran, B. Oligosphaeridium djenn, C. Coronifera oceanica, E and F. Florentina reticulate (Davey and Williams); D. Foraminiferal test lining, G and H. Pediastrum; I and J. Dityophilidites harrisii; K. Gleicheniidites senonicus; L. Droseridites senonicus; M. Distaverrusporites Florentina berran; B, E and F. Florentina reticulate,C. Coronifera oceanica; simplex; N. Cupuliferolenites; O. Gleicheniidites senonicus. P. Well-preserved wood.; Q, Cuticle with stomata; R. Degraded phytoclasts; S. Tracheid particles with visible pitings; T. AOM.*(Bar scale represents 25 μm)

Table 5. Geochemical result for elements of N, C, TIC, TOC, and C/N ratio for the analysed samples from Tsintsire 1 (NL4) section.

Sample ID	Wt. %total N	Wt. %total C	%TIC	TOC	C/N
NL4 S1	0.05	0.76	0.22	0.54	10.80
NL4 S2	0.03	0.72	0.39	0.33	11.00
NL4 S3	0.06	0.53	0.02	0.51	8.50
NL4 S4	0.07	0.51	0.01	0.50	7.14
NL4 S5	0.03	0.46	0.27	0.19	6.33
NL4 S9	0.06	1.16	0.79	0.37	6.17
NL4 S11	0.05	1.32	0.80	0.52	10.40
NL4 S13	0.04	2.20	0.20	2.00	50.00
NL4s14	0.03	4.72	0.28	4.44	148.00
NL4 S17	0.06	0.55	0.01	0.54	9.00
NL4s19	0.08	0.47	0.00	0.47	5.88
NL4s20	0.03	7.57	0.17	7.40	246.67
NL4 S21	25.00	0.54	0.02	0.52	0.02
NL4s22	0.06	0.39	0.00	0.39	6.50
NL4s23	0.02	4.73	4.61	0.12	6.00
NL4s24	0.09	0.39	0.00	0.39	4.33
NL4s25	0.07	0.51	0.00	0.51	7.29

NB: N=Nitrogen, C=Carbon, TIC= Total Inorganic Carbon, TOC, Total Organic Carbon, C/N= Carbon/Nitrogen ratio.

Table 6. Geochemical result for elements of N, C, TIC, TOC, and C/N ratio for the analyzed samples from Gundenyi (NL8) section.

Sample ID	**Wt. %total N**	**Wt. %total C**	**%TIC**	**TOC**	**C/N**
NL8s1	0.08	0.78	0.00	0.78	9.75
NL8 S2	0.01	1.23	1.08	0.15	15.00
NL8 S4	0.03	0.49	0.01	0.48	16.00
NL8 S7	0.06	0.33	0.01	0.32	5.33
NL8 S9	0.05	0.47	0.02	0.45	9.00
NL8s11	0.08	0.41	0.00	0.41	5.13
NL8s12	0.02	10.65	10.64	0.01	0.50
NL8s13	0.03	0.64	0.24	0.40	13.33
NL8s14	0.06	0.56	0.00	0.56	9.33
NL8 S15	0.04	0.43	0.01	0.42	10.50
NL8 S16	0.01	7.13	6.56	0.57	57.00
NL8s17	0.07	0.33	0.00	0.33	4.71
NL8s18	0.03	7.33	6.21	1.12	37.33

NB: N = Nitrogen, C = Carbon, TIC = Total inorganic carbon, TOC = Total organic carbon, C/N = Carbon/Nitrogen ratio.

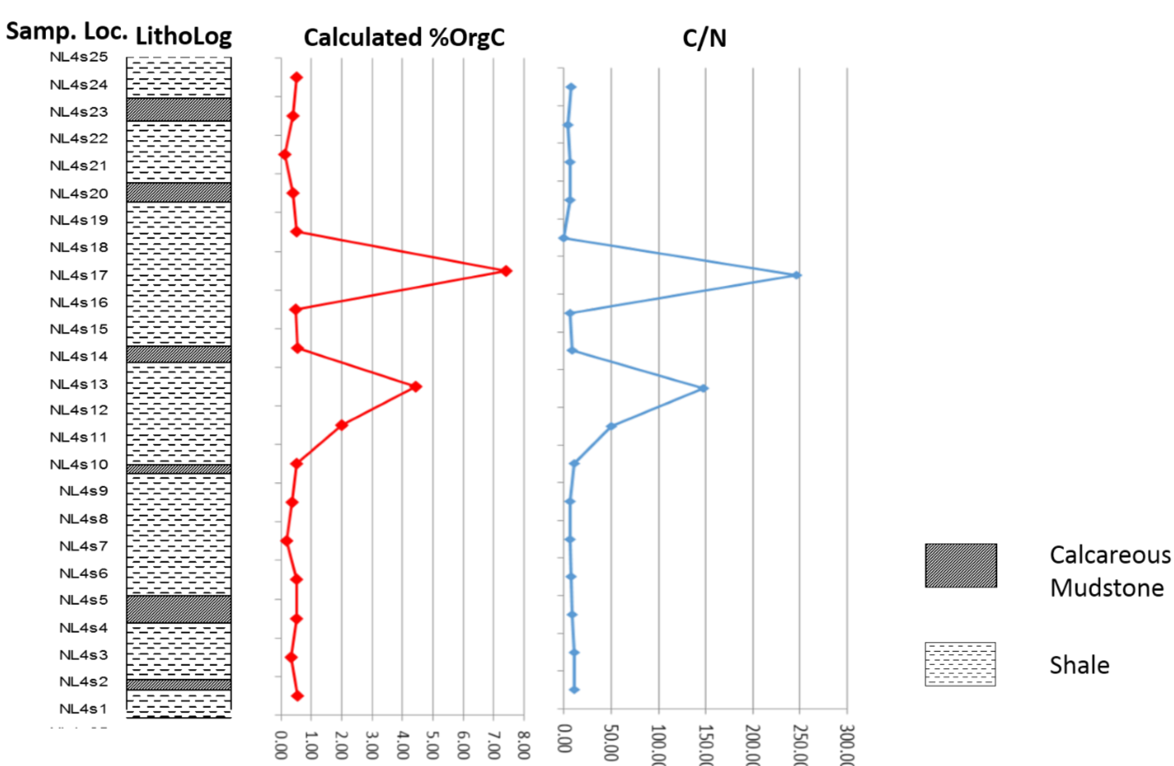

Figure 9. Plot of TOC and C/N ratio against the lithology of Tsintsire (NL4) section.

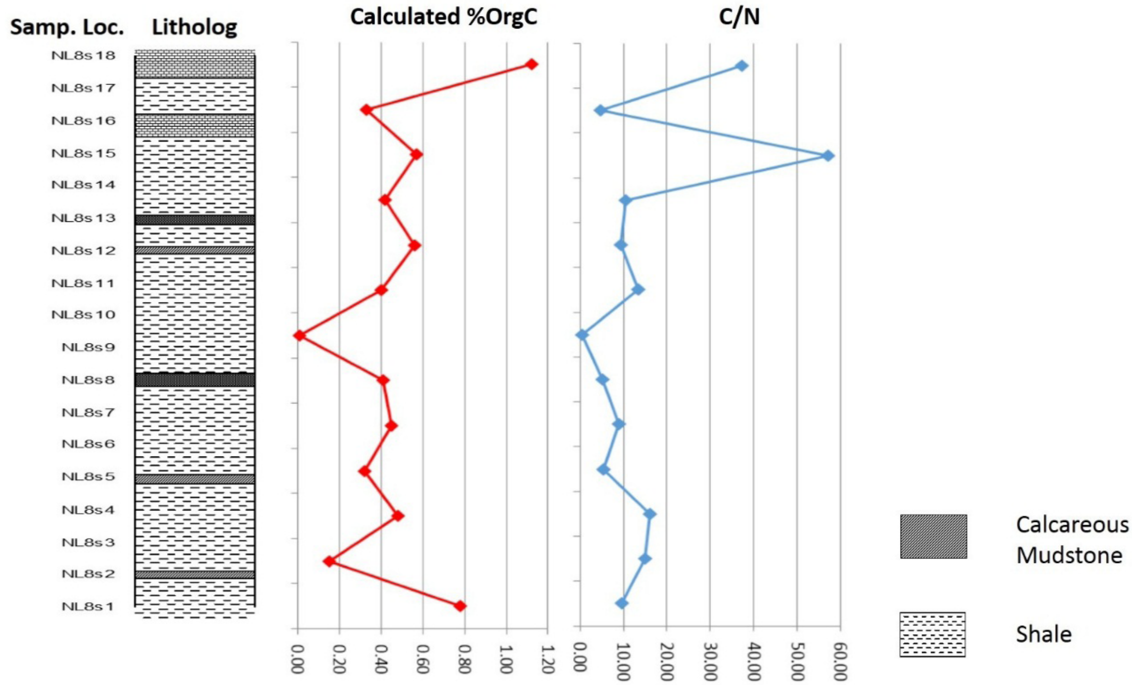

Figure 10. Plot of TOC and C/N ratio against the lithology of Gundenyi 1 (NL8) section.

(Fig. 12). The concentration of the phytoclasts group at the apex of the ternary supports the idea of a strong terrestrial influx into the basin.

Table 7. Geochemical result for elements of N, C, TIC, TOC, and C/N ratio for the analyzed samples from Kurnyi (NL10) section.

Sample ID	Wt. %total N	Wt. %total C	%TIC	TOC	C/N
NL10 S1	0.04	0.46	0.01	0.45	11.25
NL10 S3	0.04	0.72	0.01	0.71	17.75
NL10 S5	0.05	0.50	0.01	0.49	9.80
NL10 S7	0.04	0.51	0.01	0.50	12.50
NL10 S9	0.04	0.63	0.01	0.62	15.50
NL10s10	0.02	4.36	3.98	0.38	19.00
NL10s11	0.07	0.59	0.00	0.59	8.43
NL10s12	0.03	2.02	1.68	0.34	11.33
NL10 S13	0.06	0.71	0.01	0.70	11.67
NL10 S14	0.01	1.47	1.19	0.28	28.00
NL10 S15	0.03	0.40	0.01	0.39	13.00
NL10 S16	0.01	2.13	1.80	0.33	33.00
NL10 S17	0.05	0.57	0.01	0.56	11.20
NL10s18	0.02	1.06	0.74	0.32	16.00

NB: N = Nitrogen, C = Carbon, TIC = Total inorganic carbon, TOC = Total organic carbon, C/N = Carbon/Nitrogen ratio.

The Kurnyi section (NL10) contains a moderate amount of AOM and opaque phytoclast. It is hereby considered to indicate deposition in a distal but oxic shelf. A high relative percentage of opaque particles is usually derived from three main processes according to Tyson (1993). These are: oxidation of translucent woody, fragments during prolonged transport, post-depositional alteration, and natural wildfires (charcoal).

The NL8 section is characterized by a high amount of structured and degraded phytoclast. High percentages of phytoclast are mostly related to proximal depositional conditions. The main controlling factor is the short distance over which particles have been transported. Other factors, such as oxidizing conditions and relative resistance of lining tissues are also associated with the proximity of the source area (Mendonça Filho et al. 2002). Generally, large amounts of phytoclast particles are deposited by rivers in estuarine and close to the shoreline. However, deposition also occurs by a turbidity current in deep waters (Habib, 1982) The (NL4) shows variations in the temporal distribution of the palynofacies reflecting environmental changes associated with variations in the shoreline position that influence the amount of terrestrial influx into the marine environment. The shoreline shift is noticeable in three horizons where marine palynomorphs increased, depicting sea-level rise. However, the opaque phytoclast domination indicates deposition in a marginal marine.

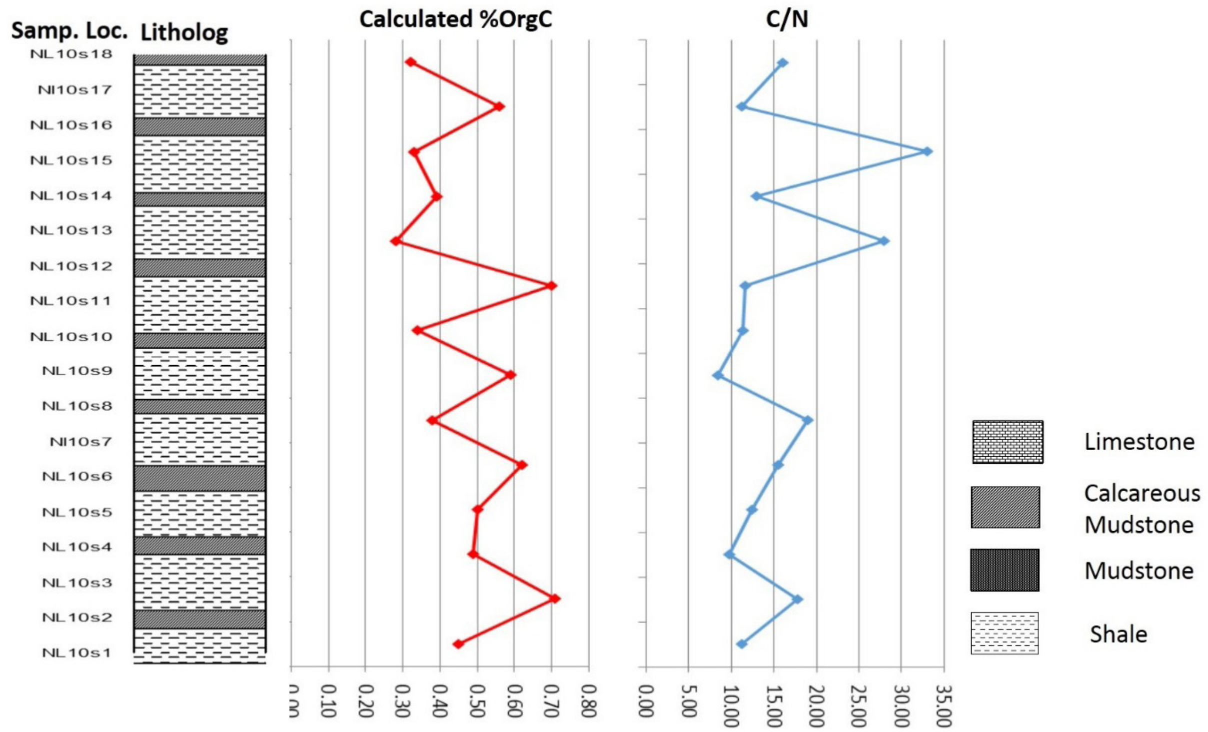

Figure 11. Plot of TOC and C/N ratio against the lithology of Kurnyi (NL10) section.

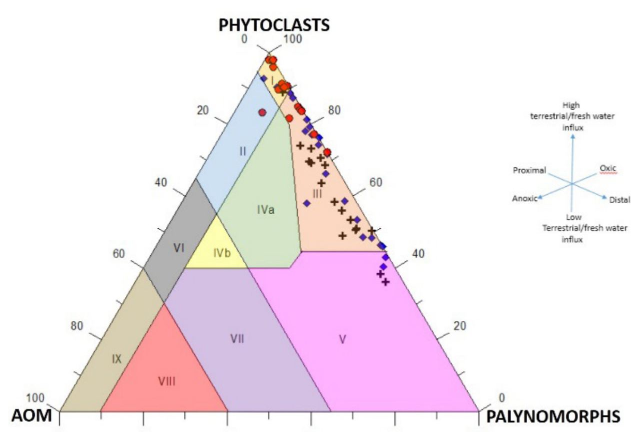

Figure 12. Palynofacies derived by plotting the frequency of palynofacies components on Tyson's amorphous organic matter–phytoclasts–palynomorphs (APP) diagram.

4.3. Total organic carbon

The abundance of organic matter in sediments is usually expressed as the relative percentage of organic carbon on a dry weight basis. This study revealed the TOC values of the samples for the three sections of the Numanha Formation to range from 0.12 to 7.40 wt. %. The NL10 section has consistent stratigraphic TOC higher than the minimum value of 0.5 wt. % for shale and at least 0.3 wt. % for carbonates (Tissot and Welte, 1984). The NL8 section fluctuates between fair to good organic matter richness while the NL4 section has fair percentages except for samples NL4s13, NL4s14, and NL4s20 which have higher values. The general low percentage of TOC may be due to the poor preservation potential of the environment of deposition as well as the oxygenated conditions that prevailed.

4.4. Carbon: nitrogen ratio

Elemental C/N ratios from sediments' TOC provide useful information for reconstructing the sources of organic matter deposited in ancient environments. Meyer (1994) indicated that in appropriate environments (not diagenetically altered), C/N ratios retain paleoenvironmental information for millions of years and can also differentiate between organic material derived from algae and vascular land plants because land plants include abundant support tissue that increases their C/N ratios above 20, whereas algae lack abundant support tissue and typically have ratios between 4 and 10. In this study, C/N ratios were mostly below 20 for the analyzed samples from all the sections which confirm the inferred marine depositional setting. There were some exceptionally high C/N anomalies observed in all of the three studied sections but more pronounced in the NL4 (NL4s13, NL4s14, NL4s20) section. Those horizons had elevated C/N ratios and are therefore interpreted to represent periods of increased terrestrial input probably as a result of high continental runoff associated with selective diagenetic consumption of nitrogen by microbial degradation.

5. Conclusion

The studied samples from the Numanha Formation revealed inferences that can be summarized as follows:

- That the study of the particulate organic matter revealed the predominance of the phytoclast group over palynomorph and AOM groups. This condition is usually related to proximal (shallower water) depositional conditions resulting from the short distance over which particles have been transported. Oxidizing conditions and relative resistance of tissues were also considered to be responsible for the high abundance of the phytoclast. Generally, large amounts of phytoclast particles are deposited by rivers in estuarine and deltaic environments both of which are close to shorelines. The phytoclast–palynomorph–AOM ternary diagram of Tyson (1995) revealed proximal to distal oxidizing paleoenvironmental conditions for the sediments.

- C/N ratios for the studied sediments of the Numanha Formation indicated marine sources for the organic matter (C/N ≤ 20). However, there are horizons that have been influenced by terrestrial sources as confirmed by the palynofacies result. Those horizons were inferred to be due to high continental runoff and selective diagenetic consumption of nitrogen by microbial degradation.

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