

Preliminary evaluation of major and trace elements content of Cretaceous – Palaeogene Formation of the Sokoto Basin, Northwestern Nigeria

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PRELIMINARY COMMUNICATION

No. of 21 shale, limestone and gypsum samples belonging to the Palaeocene Sokoto Group and 19 sandstone, shale, lignite and gypsum samples from Maastrichtian age the Rima Group of the Sokoto Basin were collected from five traverses across hills and pits, and analyzed for major and trace elements using XRF and AAS analytical techniques. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio of the Taloka Formation in the Rima Group is high (3.48 - 21.60 wt%), indicating higher silt contents while in Dukamaje Formation in the same group the ratio is low (4.60 - 5.9 wt%), indicating lower silt content. The high concentration of Fe_2O_3 of the Taloka Formation coupled with the lignite occurrence suggests a deposition under a reducing environment. The Dukamaje Formation is generally calcareous shale with gypsum seam/beds which points to marine environment. Major elements in the Palaeocene sediments indicates low silt contents and a tendency towards marine conditions as reflected in its low $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio (1.37 - 5.80 wt%). The higher Fe_2O_3 content (average > 4 wt%) indicate a reducing environment of deposition. Utilizing the discriminant function diagram for provenance signatures of the sediments using major elements shows that samples of Sokoto Group have intermediate to mafic igneous provenance while the Rima Group sediments have quartzose sedimentary to mafic igneous provenance.

Key words: Sokoto Basin, elemental analysis, provenance, Cretaceous-Palaeogene

1. INTRODUCTION

The Maastrichtian Rima Group and the Palaeocene Sokoto Group of sediments outcrops in the Sokoto Basin in northwestern Nigeria, and forms the southeastern sector of the Iullemeden Basin. The latter is one of the young Mesozoic-Cenozoic inland cratonic sedimentary basins of West Africa. The Rima Group is deposited by Maastrichtian marine transgression and is overlain by sediments of the Sokoto Group.

Several authors including^{2, 4, 7, 9, 13, 20} studied the Cretaceous and Palaeogene sediments of the Sokoto Basin. The sediments are observed to be dipping gently and thicken gradually towards the northwest, with a maximum thickness of over 1 000 metres near the frontier of the Niger Republic. These authors have suggested several geological successions. The previous work covers mainly the stratigraphy, sedimentology, palaeontology and geochemistry of the Basin. Ref.1 used palaeontological aspect in the determination of depositional environment. But major and trace elements have not been used in the determination of the origin and depositional environment of these sediments. Major and trace elements are of great importance in ascertaining the origin and depositional environment of sediments within a basin. This can be used in conjunction with other results like TOC, rock evaluation parameters and petrographic study to determine the potential of basins as source rock for petroleum. Major and trace elements have been used

to ascertain origin and depositional environments in other basins in Nigeria, e.g., Benue Trough.^{1,5}

The aim of this study is to investigate the provenance and environment of deposition of the upper Cretaceous to Palaeocene sediments of Sokoto Basin using major and trace elements. This involves evaluation of elemental variations, sediments maturity, application of discriminant function for provenance etc.

1.1. Location map

The study area lies between latitudes 10°55' and 13°52' N and longitudes 5.00° and 6.00° E in north-western part of Nigeria (Figure 1). The study area covered is about 59 570 km² and is easily accessible through network of roads. Geomorphologically, this area is generally gentle, with occasionally tabular hills, capped by resistant laterites. Elevation generally decreases towards the northwest around the Nigeria-Niger Republic border with an average elevation of about 215 m.

1.2. Geological settings

The Iullemeden Basin is entirely a cratonic basin created by tectonic progradational movements or stretching and rifting of tectonically stabilized crust during the Palaeozoic.² These movements become evident from the beginning of Palaeozoic and continued until the Upper Cretaceous when the opening of the Goa Trench was achieved.⁸ These movements are responsible for the SW progradation of the sediments deposited within the ba-

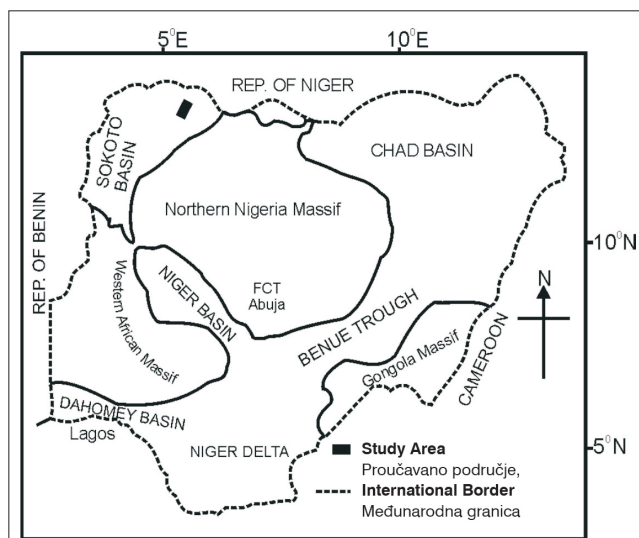


Fig. 1. Geology map of Nigeria showing study area
 Sl. 1. Geološka karta Nigerije s prikazanim proučavanim područjem

sin. They become progressively younger as one moves towards the SW (Nigeria) from north where it is referred to as the Sokoto Basin (Figure 1).

In northwestern Nigeria, the sediments of the Iullemeden Basin were deposited during three main phases of deposition which include the continental Mesozoic and Cenozoic phases, with an intervening marine Maastrichtian to Palaeocene phase. The sedimentary rocks of the Sokoto Basin have been classified into four main groups (Table 1). The pre-Maastrichtian (Lower Cretaceous) sediments are of fluvial and lacustrine origin. They belong to the Gundumi and Illo Formations which extend northwards into the Republic of Niger. The second phase in the depositional history of the northwestern Nigerian basin began during the Maastrichtian when the Rima Group was deposited unconformably on the Lower Cretaceous sediments as the Taloka, Dukamaje and Wurno Formations. The Taloka Formation also referred to as the lower sandstone and mudstone and lignite⁹, consists of interbedded grey to dark brown mudstone and light coloured, medium to fine-grained sand with some thick bands of carbona-

ceous shale or lignite.¹¹ The Dukamaje Formation consists predominantly of shales with some limestone and mudstones. The shales contain numerous fragments of vertebrate and limb-bones. A richly fossiliferous bone bed lies near the base. In refs.^{10, 13} stated that the Dukamaje Formation is locally gypsiferous. The Wurno Formation consists of thin, friable, fine-grained sandstone intercalated with soft mudstone and siltstones.¹¹ It is very similar to the Taloka Formation.

The Rima Group is overlain by the Sokoto Group belonging to the Upper Palaeocene age.¹⁶ The Sokoto Group consists of three formations (Table 1) namely Dange Formation (oldest), Kalambaina Formation and Gamba Formation (youngest). The Dange Formation forms the base of the Sokoto Group of sediments. It consists of slightly indurated bluish grey shale interbedded with thin layers of yellowish brown limestone. The contact between the Wurno Formation (Maastrichtian) and Dange Formation (Palaeocene) can be seen at Dange village, characterized by a well-exposed erosional plane marking the top of the Wurno Formation. The contact marks the Cretaceous-Palaeogene boundary.

The Kalambaina Formation (Table 1) overlies the Dange Formation. It consists of white, marine, clayey limestone and shale. The formation is rich in vertebrate fossils.^{11,21,25} The name Gamba Formation was proposed by.¹² The formation consists of grey laminated shale overlying the calcareous Kalambaina Formation. The shales appear to be folded due to removal by solution of the underlying limestone and the slumping of the overlying beds.

The Upper Palaeocene marine sediments of Sokoto Group are overlain disconformably by a thick series of deposits consisting predominantly of red and mottled massive clays with sandstone intercalations. These sediments belong to the Gwandu Formation with its type section and type area (lat. locus typicus) in the Gwandu emirate of Nigeria.¹¹ Ref.¹⁷ assigned a possible Eocene age to the Gwandu Formation based on palynological parameters.

2. METHODOLOGY

The methodology of this study involves two phases. These are field study for sample collection and laboratory analyses.

Table 1. Summary of Geological sequence in the Sokoto Basin ¹⁵			
AGE	FORMATION	GROUP	DEPOSITIONAL ENVIRONMENT
Eocene to Palaeocene	Gwandu Formation	Sokoto Group	Continental
Upper Palaeocene	Gwandu Formation Kalambaina Formation	Sokoto Group	Marine
Maastrichtian	Wurno Formation Dukamaje Formation Taloka Formation	Rima Group	Brackish water with short period of marine regimes
-----	Unconformity	-----	-----
Most Lower Cretaceous or older sediments	Illo and Gundumi Formations	—	Continental
-----	Major Unconformity	-----	-----
Precambrian	Basement Complex		

2.1. Field study and sample collection

Rock outcrops in the area were studied across hills and pits and representative samples were collected for further laboratory analysis. For the Sokoto Group, 21 samples were collected from outcrops in two villages; Dange and Kalambaina via Sokoto. For the Rima Group, 19 samples representing two major formation namely; Taloka Formation (14 samples) and Dukamaje Formation (5 samples), were collected from three profiles. Spot sampling method was used in the field for sampling. Detailed composite lithologic descriptions of the samples were made.

2.2. Laboratory analyses

This involves determination of major and trace elements using x-ray fluorescence (abbr. XRF) and Atomic Absorption Spectrophotometric (abbr. AAS) methods. X-ray fluorescence method was used to determine the concentration of major element in order to infer the environment of deposition. The samples were pulverized for 60 seconds using Herzog Gyro-mill (Simatic C7-621). Pellets were prepared from the pulverized sample; first by grinding 20 g of it with 0.4 g of stearic acid for 60 sec. Stearic acid is an organic binder which increases mechanical stability of the sample. The 2 mm thick pellets were loaded into each sample holder of the x-ray machine (Phillips PW-1660) for analysis. This method operates on the principle of atomic physics and quantum chemistry. The specimens were exposed to the entire spectrum of photons consisting of primary radiation emitted from a standard x-ray tube which irradiated each specimen causing the element in it to emit secondary fluorescence with their characteristics x-ray line spectra. The spectral line energies or wavelength of the emitted lines was used in the quantitative analysis of elements in the specimen. The intensities of the emitted lines were related to their elemental concentration.

2.3. Atomic Absorption Spectrometry (AAS)

This method is described in details by²³ It is used for the determination of light elements with atomic numbers too low to be measured by XRF. Atomic absorption spectrophotometry is based upon the observation that atoms of an element can absorb electromagnetic radiation. This occurs when the element is atomized and the wavelength of light absorbed is specific to each element. The rock samples collected were air dried thoroughly. A representative rock sample of each was pulverized into fine powdered of about 100-mesh size using a mortar and pestle. The mortar and pestle were washed and dried after grinding each sample so as to avoid contamination. The pulverized samples were carefully kept in small labelled test tubes to avoid miss-representation.

Wet method of digestion in nitric acid was used to determine TiO_2 and the trace elements. In wet digestion method, 0.5 g of powdered rock sample was weighed into a dry digestion tube, 3 to 4 drops of distilled water was added to wet the sample. 5 ml of hydrochloric acid (HCL)

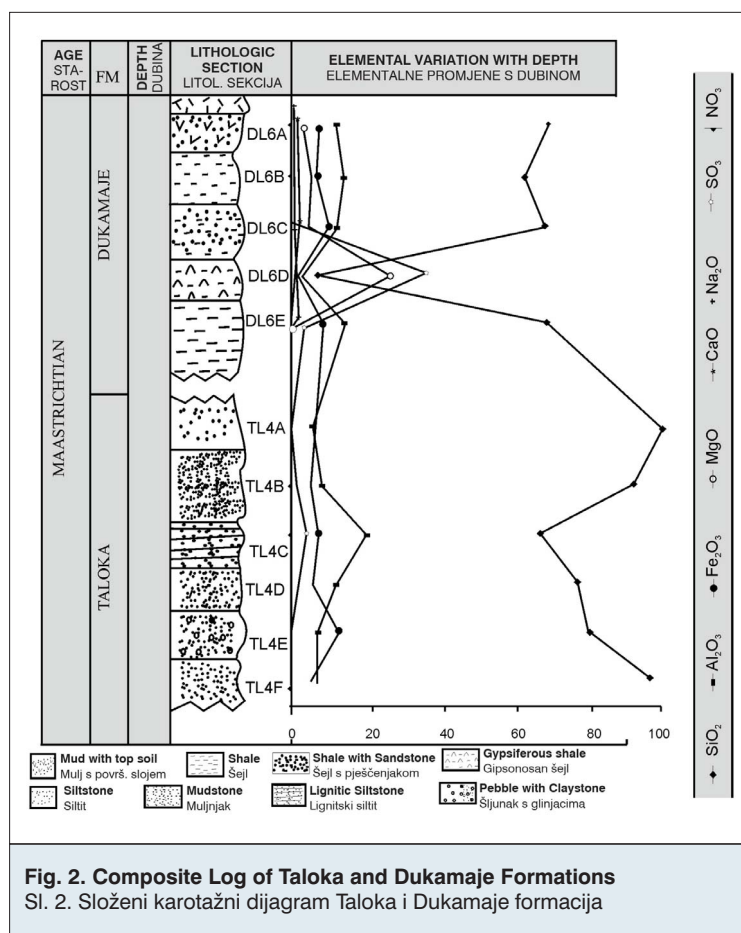


Fig. 2. Composite Log of Taloka and Dukamaje Formations
Sl. 2. Složeni karotažni dijagram Taloka i Dukamaje formacija

was added and the solution was stirred. 5ml of nitric/perchloric acid was prepared in the ratio of 3:2 and was added and stirred. The tube was left to stay overnight without heating.

The samples were digested at temperature of 120 °C on a hot water bath inside a fume cupboard. The solution was heated strongly until there was no fume coming out of the beaker. The samples were leached out with 5 ml of 6M hydrochloric acid (HCL) into a graduated test and were made up to 20 ml with distilled water. The content was shaken vigorously to avoid caking and the resulting solutions were referred to as the stock solution. All the test tubes were correctly labelled. The solutions were used directly to determine TiO_2 and all the trace elements using AAS.

3. RESULTS AND INTERPRETATION

The results of major and trace element analysis are tabulated and used in interpretation of the environment of deposition and source of the sediments.

3.1. Elemental analytical results

Important oxides analyzed in the study include SiO_2 , MgO , Na_2O , K_2O , SO_3 , TiO_2 , CaO , NO_3 , Al_2O_3 , Fe_2O_3 and FeO . SiO_2 , CaO , Fe_2O_3 and Al_2O_3 account for between 80% concentration in the samples. The Maastrichtian samples are dominantly rich in SiO_2 , Al_2O_3 and Fe_2O_3 , and these major elements account for between 91.28% to

Table 2. Major and Trace Elements Result of the Maastrichtian Rima Sediments in Sokoto Basin

Sample No	TL3A	TL3B	TL3C	TL4A	TL4B	TL4C	TL4D	TL4E	TL4F	TL5A	TL5B	TL5C	TL5D	TL5E	DL6A	DL6B	DL6C	DL6D	DL6E	
	MAASTRIC TIAN																			
Age	DUKUMA E																			
Formation	TALOKA																			
ELEMENTAL OXIDE (WT%)	SiO ₂	84.01	70.46	75.54	99.38	91.53	66.62	76.57	79.29	95.89	85.71	89.62	92.65	88.45	80.43	70.11	63.61	68.44	65.55	69.02
	Al ₂ O ₃	5.07	5.12	12.66	4.60	6.92	19.15	10.54	5.25	5.39	7.27	6.60	6.02	5.55	10.07	11.96	13.92	11.86	2.21	14.18
	Fe ₂ O ₃	6.13	19.63	4.30	5.30	3.54	5.51	4.18	11.32	3.46	3.95	3.36	3.19	3.14	3.83	7.22	6.11	9.83	0.94	7.92
	MgO	0.02	0.58	0.22	0.22	0.07	0.36	0.33	0.09	0.07	0.24	0.07	0.06	0.01	0.20	1.20	1.81	1.34	0.42	1.95
	CaO	0.12	0.03	0.13	0.24	0.04	0.72	0.11	0.30	0.21	0.30	0.14	0.04	0.07	0.42	2.70	5.51	4.27	26.70	2.33
	Na ₂ O	0.08	0.00	0.20	0.01	0.00	0.02	0.01	0.13	0.00	0.05	0.01	0.01	0.03	0.03	0.12	0.19	0.17	0.02	0.12
	K ₂ O	0.07	0.12	0.11	0.07	0.07	0.13	0.16	0.09	0.10	0.17	0.08	0.09	0.07	0.15	0.45	0.89	0.66	0.09	1.00
	SO ₃	0.14	0.11	0.05	0.13	0.06	2.59	2.04	0.49	0.53	1.02	0.11	0.08	0.16	0.15	0.12	0.33	0.40	36.11	1.31
	LOI	5.38	8.18	7.11	1.31	2.72	24.50	10.74	7.86	20.92	6.00	2.53	2.39	4.89	5.06	12.70	14.68	16.52	21.79	18.65
	SiO ₂ /Al ₂ O ₃	16.57	13.76	5.97	21.60	13.32	3.18	7.26	15.10	17.79	11.79	13.58	15.39	15.94	7.99	5.86	4.57	5.77	2.96	4.87
Na ₂ O/K ₂ O	1.14	0.03	1.82	0.14	0.06	0.15	0.06	1.44	0.04	0.29	0.13	0.11	0.43	0.20	0.27	0.21	0.26	0.22	0.12	
TRACE ELEMENTAL (ppm)	Cr	3.90	2.90	3.30	2.80	3.10	4.40	3.40	3.10	4.30	3.20	4.30	3.90	4.60	2.60	4.90	4.10	4.80	2.90	4.20
	Ni	2.60	1.80	2.40	2.10	2.30	2.30	2.10	2.10	2.00	2.40	2.20	2.60	1.30	2.10	2.60	2.10	2.00	2.00	2.90
	Ba	5.40	4.90	4.40	4.60	5.20	4.50	4.90	5.80	4.80	5.20	5.00	6.10	5.20	5.10	5.10	4.90	5.10	6.30	2.20
	n	9.70	10.00	10.00	5.60	12.00	13.00	9.40	7.60	8.70	15.00	8.80	8.40	8.60	11.00	8.00	7.30	9.30	8.40	5.80
	Cd	8.00	8.30	7.80	6.70	5.90	8.40	7.60	7.10	6.60	7.20	9.10	7.10	8.70	7.50	8.60	9.00	7.20	8.10	5.20
	Pb	6.70	9.50	6.30	8.70	9.00	7.10	6.10	3.60	8.40	8.60	7.70	5.00	6.90	4.70	7.80	8.10	9.40	7.50	7.40
	Cu	5.70	5.20	3.50	3.00	6.10	4.00	3.00	3.10	5.30	4.50	8.60	5.40	3.40	4.00	4.50	5.00	4.30	6.70	4.20
	As	1.30	1.60	1.70	0.90	1.30	1.90	1.60	1.80	1.10	1.40	1.20	1.20	1.80	1.30	1.00	1.40	1.40	1.50	1.00
	g	3.00	3.20	3.20	3.20	3.40	2.80	2.80	3.40	3.00	3.20	4.00	3.00	4.00	3.50	3.60	3.20	2.70	2.00	3.20

99.58% of the samples. Table 2 shows results of major and trace elemental analysis respectively for Taloka and Dukamaje Formations. The Taloka Formation has higher SiO_2 values than the Dukamaje Formation, which is a reflection of differences in lithological component due to the differences in environment of deposition. With the exception of Taloka lignite, the Dukamaje Formation, which contain mud-shale suite has a little higher Al_2O_3 values than Taloka Formation. Figure 2 shows the composite log of Dukamaje and Taloka Formations. The siltstone at the top and mudstone at the base of the Taloka Formation yield the highest concentration of SiO_2 values (99.38% and 95.89% respectively).

There is corresponding decrease in the Al_2O_3 values at these two levels which gives the formation a high $\text{SiO}_2/\text{Al}_2\text{O}_3$ except for the Lignite samples (Figure 2). Generally, the ratio of $\text{SiO}_2/\text{Al}_2\text{O}_3$ is high in all the samples from the Taloka Formation but low in samples from the Dukamaje Formation. That formation contains more CaO than the Taloka Formation because the former is made up of calcareous organic matter probably from marine environment. Generally, concentration of Fe_2O_3 in the Taloka Formation is high (average of 5.79%), which may be from the source rock, indicating the source rock to contain some appreciable biotite and hornblende. It may also be an indication of oxidation condition. The Taloka lignite and siltstone (TL4D) show more concentration of SO_3^{2-} (2.57% and 2.04% respectively), which may be due to the mode formation of these beds which are deposited under anoxic condition. Ref.²¹ described anoxia to probably result from bottom water stagnation due to the density stratification caused by a high input of terrigenous organic matter and poor circulation.

Table 3 shows the results of geochemical analysis obtained from samples of the Palaeocene sediments. SiO_2 , CaO, Fe_2O_3 and Al_2O_3 account for between 75% and 90% concentration in the samples. The SiO_2 values ranges from 57.79 wt% to 59.98 wt% for shale samples in Gambia Formation, while this value ranges from 44.64 wt% to 62.28 wt% for samples from Dange Formation. The SiO_2 value is low, ranging from 0.3 wt% to 0.5 wt%, for limestone from the Kalambaina Formation, while gypsum samples from the Dange Formation yield a value that ranges from 11.69 wt% to 25.07 wt%. These results are indication of low siliciclastic input for the limestone and gypsum samples. Al_2O_3 ranges from 10.01 wt% to 11.81 wt% for the Gambia shales, 16.10 wt% to 21.81 wt% for Dange shales, 0.01 wt% to 0.02 wt% for limestone from the Kalambaina Formation, while it ranges from 5.41 wt% to 18.35 wt%, for gypsum samples from the Dange Formation. Clay samples from the Kalambaina Formation have Al_2O_3 values that range from 7.63 wt% to 30.30 wt%. Alumina is a good maturity index. [20] regarded clay sediments as washed product of weathering and presumed that alumina, as least mobile oxide, will tend to be in the most matured weathered residuum. The high alumina content in sediments from Dange Formation shows that they are the most matured of the rock samples analyzed. F_2O_3 value ranges from 6.60 wt% to 7.45 wt% for the Gamba shales, 5.12 wt% to 6.82 wt% for the Dange Shales, and 4.69 wt% to 6.28 wt% for gypsum sample in

the Dange Formation while its value is low, ranging from 0.37 wt% to 0.38 wt% for the Kalambaina Limestone.

Trace element contents were determined to assess possible relationships across stratigraphic profile. Three groups of trace element associations can be identified from the Taloka Formation. The first group consists of Zn, Cd, Cr and As, (Table 2) where they show highest concentration in the Taloka lignite (TL4C). This may be due to low energy condition during the deposition of the sediment, where processes of chemical transformation were greatly retarded. Leaching and weathering may be the factors that reduced the concentration of this group. The second group consists of Ba, Cu and Hg (Table 2). They show a decrease in concentration in the Taloka Lignite (TL4C). The trends shown by both groups of trace elements across the profile (Figure 2) reveal probably by difference in energy condition during deposition and environment of deposition across the stratigraphic profile. Ni falls into the third group, which shows no systematic variation with either lithology or depth, and the concentration is between 1.30 and 2.60 ppm.

The Dukamaje Formation shows decrease in concentration of Ba, Cu, Cd, Zn and Pb with depth. Sample No. DL6E shows the least concentration for the above trace elements, which may be due to leaching and diagenesis. The concentration of Ba is between 2.20 and 6.30 ppm while those of Zn and Pb are between 5.80 and 9.30 ppm, and 7.40 and 9.40 ppm, respectively. Cd concentration in the Dukamaje samples analysed is between 5.20 and 9.00 ppm and decreases with age (Table 2), thus supporting¹⁹ hypothesis which states that Cd concentration are greater in younger than the older sediments. Gypsiferous shale (DL6D) shows an increase in the concentrations of Cu, Ba and Zn, and a decrease in the concentration of Cr, Hg and Pb, which may be due to the mode of deposition of the sediment.

3.3. Depositional environments

The result of the major elements analysis shows the Taloka Formation consisting predominantly of SiO_2 , Al_2O_3 and Fe_2O_3 , which is an indication of high silt content. The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio also supports this. This means that the sediments are almost entirely fine-grained, usually mud, consisting of silt which is a characteristic pattern of distribution of tidal-flat sediments. Near the high water line and water shed, sediments are muddy and clayey. While near the low water line, the sediments are sandy. The reasons for this characteristic pattern of sedimentation of tidal-flats are because of the energy and partly the transport mechanism. Near the low water line, the wave activity is strongest and active. It last longest as compared to higher parts of the intertidal zone; thus, the sand is enriched here. Lignite bed occurs at Taloka village, the type section for the Taloka Formation. The lignite yields the highest concentrations of SO_3 which is an indication of enriched presence of organic matter. Lignite occurrence is also of special environmental significance as it confirms the paralic nature of the depositional environments during the Maastrichtian in the Sokoto Basin.

The samples of the Dukamaje Formation consisting of laminated and non-laminated shales with thin bands of gypsum, represents the deeper marine sediments of the

Table 3. Major Elements Results of Paleocene Sokoto Sediment in Sokoto Basin

	Formation	Dange	Kalambina	Gamba						
	Age	Lower Paleocene			Middle Paleocene		Upper Paleocene			
	Lithology	Claystone	Shale	Gypsum	Shale	Limestone	Shale	Limestone	Marl	Clay
ELEMENTAL OXIDES (wt%)	SiO ₂	37.56	61.47	25.07	59.98	0.30	57.79	0.50	17.51	60.16
	Al ₂ O ₃	7.63	16.00	18.35	11.81	0.01	10.01	0.02	4.92	19.63
	FeO ₃	2.48	7.31	6.28	6.60	0.38	7.45	0.37	1.55	5.19
	FeO	0.0014	0.0817	0.001	0.0017	0.0033	0.002	0.004	0.003	0.0013
	CaO	39.64	1.67	21.80	1.19	54.56	2.12	55.04	41.03	0.94
	MgO	1.80	1.96	1.52	6.81	0.34	7.63	0.37	2.22	1.15
	K ₂ O	0.17	1.13	0.66	0.43	0.05	0.43	0.05	0.22	1.12
	Na ₂ O	0.73	0.10	0.01	0.44	0.01	0.11	0.01	0.04	0.09
	SO ₃	0.10	0.05	7.18	0.08	0.04	0.08	0.05	0.04	0.08
	TiO ₂	0.004	0.0008	0.001	0.0005	0.003	0.001	0.00004	0.00004	0.00009
	NO ₃	0.005	0.003	0.004	0.006	0.005	0.0014	0.005	0.004	0.004
	LOI	10.17	8.68	18.45	12.95	44.30	14.30	43.61	31.46	11.08
	Total	100.02	99.55	99.33	99.99	100.0	100.00	100.03	99.46	99.99
	SiO ₂ /Al ₂ O ₃	4.92	3.84	1.37	5.07	30	5.8	2.5	3.6	3.1

same sea. The major elemental interpretation shows these shales to have low concentration of SiO₂ and high concentration of Al₂O₃, therefore the SiO₂/Al₂O₃ ratio is low. This is an indication of low silt content which probably infer marine environment. There is also high concentration of CaO that suggests calcareous shale, from marine environment.

The major elemental analysis of the gypsum reveals intertidal-lagoonal facies of transitional environment of deposition, probably in a lagoon cut off from sea. As a result, evaporation caused the precipitation of gypsum, which is an example of sabkha. Clay and shale units with thin band of muddy gypsum crystals were probably deposited in mud-rich sabkhas. Sediments of the mud-rich sabkhas were deposited in a belt parallel to the inner shelf and were better developed in the western side of the Sokoto Basin because of infiltration and evaporation of water in the lagoon, only mud was carried into it. However, the presence of dark phosphatic nodules, which is probably evidence of replacement of gypsum by authigenic phosphate, suggests a shallow marine environment with access to the open sea at one side, where upwelling of phosphate as nodules, laminar or replacement of various forms of gypsum took place. Where such upwelling is common, particularly along west coast of continent, cold phosphate rich water results and this leads to excessive phytoplankton bloom that poison the water and causes mass mortality of fish; upon the death of the organism more phosphate is contributed to the ocean floor via organic detritus. This is supported by the presence of fossiliferous bed that has yielded fossil bones, including crocodilian skulls, fish species, such as sharks and saw fish in the Sokoto Basin.^{9,16,25,27}

In other words, both Maastrichtian Formations are deposited in a transitional environment when the sea encroached the Sokoto Basin, during the Upper

Maastrichtian, and the Taloka Formation represents the coastal plain sands and muds of the encroaching Maastrichtian Sea while the Dukumaje Formation represent a deeper marine facies of the same sea.

For the Palaeocene sediments, the exceptionally high SiO₂, low Na₂O and K₂O content in the shale and gypsum sample is an indication of the deposition in shallow marine environment, where K₂O and Na₂O were in suspension and were later deposited further offshore.¹ The ratio of SiO₂/Al₂O₃ is low, lying between 3.1 wt% and 5.8 wt% for the Gamba and Kalambaina Formations and between 1.37 wt% and 3.87 wt% for the Dange Formation. The low value indicates lower silt content, suggesting therefore tendency toward marine condition.⁵ The clay and shale in the Dange Formation have a CaO value greater than 7.0 wt% which is indicative of a calcareous shale.³ The high alumina content in sediments from the Dange Formation shows that they are the most matured of the rock samples analyzed. Alumina is a good maturity index. Ref. ²² regarded clay sediments as washed product of weathering and presumed that alumina, as least mobile oxide, will tend to be in the most matured weathered residuum. The high values of Al₂O₃ (> 5.0 wt% on average) for the Dange and Gamba Formations is an indication of a reducing environment, while a low Fe₂O₃ for the Kalambaina Formation suggests an oxidizing depositional environment. The process of formation of iron in these sediments probably reduces iron from Fe³⁺ to Fe²⁺ + e⁻.⁶ This process takes place under a reducing environment.

Skeletal fragments of mainly gastropods and ostracods show that the sediment was deposited in a shallow water environment, probably as subtidal-lagoonal facies. The presence of ooids shows these particles have been agitated and transported by strong current, indicating a high kinetic energy in the deposition environment.

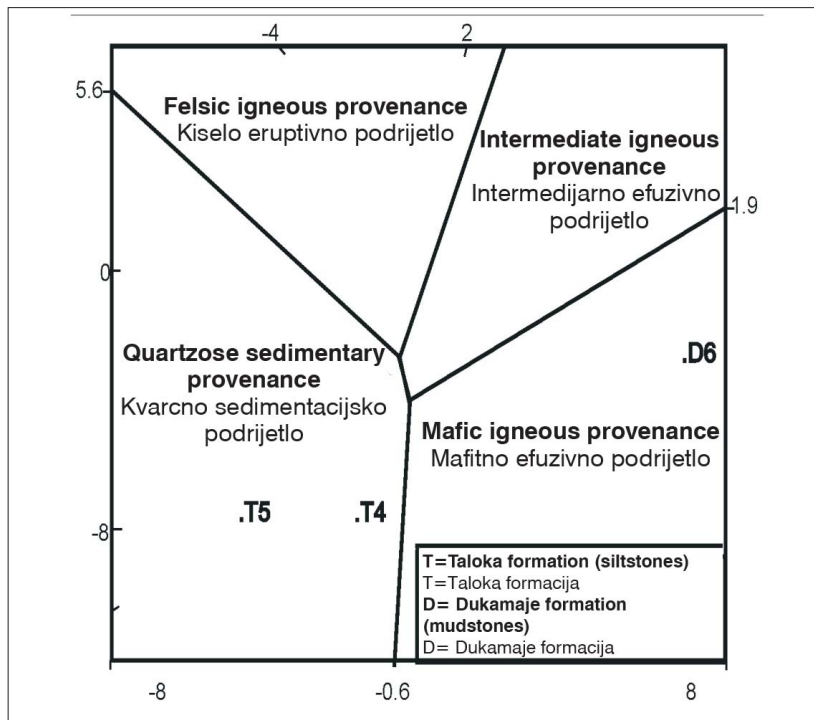


Fig. 3. Major element Discriminant Function diagram of ²⁶ for sedimentary provenance. The discriminant functions are: Discriminant Function 1 = (-1.773_TiO₂) + (0.607_Al₂O₃) + (0.760_Fe₂O₃) + (-1.500_MgO) + (0.616_CaO) + (0.509_Na₂O) + (1.224_K₂O) + (9.090); Discriminant Function 2 = (0.445_TiO₂) + (0.070_Al₂O₃) + (0.250_Fe₂O₃) + (1.142_MgO) + (0.438_CaO) + (1.475_Na₂O) + (1.426_K₂O) + (6.861).
 Sl. 3. Dijagram diskriminacijske funkcije glavnih elemenata područja napajanja sedimentnim materijalom.²⁶ Diskriminacijske funkcije su: diskriminacijska funkcija 1 = (1,773_TiO₂) + (0,607_Al₂O₃) + (0,760_Fe₂O₃) + (1,500_MgO) + (0,616_CaO) + (0,509_Na₂O) + (1,224_K₂O) + (9,090), diskriminacijska funkcija 2 = (0,445_TiO₂) + (0,070_Al₂O₃) + (0,250_Fe₂O₃) + (1,142_MgO) + (0,438_CaO) + (1,475_Na₂O) + (1,426_K₂O) + (6,861).

Though the samples are deposited in subtidal to intertidal – lagoonal environment, the high rate of deposition should have contributed to the preservation of organic matter. However, the process of reworking of sediments due to rigorous transportation near surface

weathering, and low temperature diagenetic changes may have resulted in decrease of the organic content of the sediment.

3.4. Provenance signature of the rock samples from elemental analysis

Using major oxides as variables,²⁶ established major element discriminant functions to distinguish between sediments whose provenance is primarily mafic, intermediate or felsic igneous and quartzose sedimentary. Their analysis was based upon 284 chemical analyses in which Al₂O₃/SiO₂ and Fe₂O₃ + MgO proved the most valuable discriminant. A plot of the first two discriminant functions based upon the oxides of Ti, Al, Fe, Mg, Ca, Na and K most effectively differentiate between the four Provenance. Discriminant functions are interpreted by means of standardized coefficients and the structure matrix. It helps to visualize how the two functions discriminate between groups by plotting the individual scores for the two discriminant functions.

Utilizing the discriminant function diagram shown in Figure 3, typical samples of the Taloka Formation (T3,T4,T5) plot in the quartzose sedimentary provenance, suggesting a recycled origin. The Dukumaje Formation sample (D6) fall within the mafic igneous provenance.

Table 4 shows sediments of the Dange Formation (samples 3 and 4) have mafic igneous provenance. However, the shale sample (sample No. L1A and L2A) from the Gamba Formation have quartzose sedimentary provenance. Mafic rocks are silica-deficient igneous rock (about 50% of SiO₂), with a relatively high content of magnesium, iron and calcium. The low silica content in the siliciclastic input signifies low level of clastic dilution of

Table 4. Sediments of the Dange Formation				
Sample No	Lithology	DF1	DF2	Provenance
L1A	Shale	- 7.88	-15.62	Quartzose sedimentary
1C	Marl	16.77	16.89	Intermediate igneous
1D	Clay	4.18	- 5.84	Mafic igneous
L2A	Shale	- 6.87	- 14.14	Quartzose sedimentary
L3A	Claystone	19.27	9.68	Intermediate igneous
3D	Shale	3.80	- 7.08	Mafic igneous
3E	Gypsum	12.39	1.68	Mafic igneous
L4C	Clay	14.92	- 1.58	Mafic igneous
4D	Mud	10.40	- 2.60	Mafic igneous
4E	Shale	10.28	- 3.90	Mafic igneous
4F	Gypsum	10.48	2.75	Mafic igneous

the organic matter in sediments of the Dange and Kalambaina Formations. On the other hand, the quartzose sedimentary provenance for the Gamba Shales indicates high silica input from their source. However, high value of Fe_2O_3 content for all the samples points to a reducing depositional environment. All these are favourable conditions for deposition and accumulation of organic matter.

4. DISCUSSION AND CONCLUSION

The sedimentary deposits of the Sokoto Basin in north western Nigeria lie on the Precambrian basement rocks such as gneisses, granites, phyllites and quartzites. These basement rocks outcrop in the eastern and south eastern sectors of the Sokoto Basin. The sedimentary units in the basin consist of clay, grits, mudstone, silt, silty sand, clay shale, lignite, limestone, gypsum and alluvium, which fall within different stratigraphic succession. These are divided into the Upper Cretaceous, Palaeogene and Quaternary systems/series. Some of the rock units are richly fossiliferous and have both vertebrates and invertebrate fossils.

The major elemental result of the Maastrichtian sediments which make up the Rima Group of the Sokoto Basin reveals that the Taloka Formation (Lower Maastrichtian) contains predominantly siltstones which are chemically mature and with the dominance of K-Feldspar and K-mica over albitic plagioclase. This was deposited under oxidizing conditions as suggested by the high concentration of Fe_2O_3 and the presence of a bed containing pebbles with claystone. This formation also contains lignitic bed deposited under a reducing environment. The Dukamaje Formation (Middle Maastrichtian) consists of calcareous shale deposited in a marine environment with gypsum precipitates. The trace elemental result shows a stratigraphic variation in mode of occurrence with three groups recognized for the Taloka Formation while two groups for the Dukamaje Formation. These changes are possibly related to depositional environment, age and lithological composition of the sediments.

The result of major oxides from the Palaeocene sediments made up of the Dange, Kalambaina and Gamba Formations (Lower, Middle and Upper Palaeocene respectively) indicates a reducing, shallow marine environment of deposition for the sediments. These formations make up the Sokoto Group in the Sokoto Basin. The rock type is characterized by shale, limestone and gypsum.

From the foregoing, the elemental analyses of the Maastrichtian to Palaeogene sediments of the Sokoto Basin show a reducing, intertidal-lagoonal to shallow marine environment of depositions. The discriminant functions indicate that the sediments are mainly of mafic igneous and quartzose sedimentary provenance.

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