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Mineralogy and Geochemical Characteristics of Clay Occurrence in Central Bida Basin Northwestern Nigeria

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Abstract
The Bida basin is bounded to the north and south by the Precambrian basement rocks. The largest portion of the basin occurred at the southern half of Niger State, which formed the central portion of the basin that constitutes the study area. Clay of varying mineralogical and chemical compositions has been reported to have occurred as sedimentary clays within varying lithological units and at various locations of the Bida basin. Geochemical analytical methods employ is Inductively Coupled Plasma mass spectrometer (ICP – MS) and X-ray Diffraction (X-RD). Field work revealed seven clay occurrences at different stratigraphic formations. Mineral compositions of the study clay account for Kaolinite, muscovite/illite and anatase. Geochemical results revealed SiO_2 ranging between 54.91wt% and 87.37wt%, and moderately high Al_2O_3 ranging between 7.4wt% and 29.67wt%, and a low value of Fe_2O_3 ranging between 1.13wt% and 7.11wt%. However, the samples are low in CaO, Na_2O and K_2O except for Shegba clay which is slightly higher in K_2O. Trace and rare elements suggested felsic character in the nature of source materials of the kaolin.

1. Introduction

Clay of varying mineralogical and chemical compositions has been reported to have occurred as sedimentary clays within varying lithological units and at various locations of the Bida basin. Adeleye, 1973 studied two main types of clays in Bida basin are the earthy brown to red lateritic clays and the gray ball clays, there are also the white and silty kaolinites. The lateritic clay occurs beneath thin to thick covers of laterite within sections on the mesas. Red stains of laterite are noticeable in those clays which grade into white – sandy kaolin within the peneplains. The earthy lateritic clays are ubiquitous in occurrence. The gray ball – clays within the Bida basin occur on alluvial plains of rivers, which are derived from the feldspar rich basement rocks. Braide, 1992 in his study concluded that the sedimentary deposits in Bida basin are characterised by high to low energy depositional environment in a meandering braided river system, of which thick deposits occurred where meandering is large and reported shallow depth of carbonaceous peat deposits at Kudu, Makera, and Bokani areas. Idris-Nda 2010 studied the aquifer system of the Bida basin and concluded that the sedimentary fill of the basin is the weathered product of adjoining basement materials deposited in alternating sand and clay with percentage of sand increasing to the north of lacustrine deposition environment. Brade 1992 studied the alluvial fan depositional in the northern Bida basin and repoted syn-depositional tectonic subsidence controlled responsible for upward coarsening sequence recognized in the alluvial fans. Goro *et. al.*, 2014 studied the characterization of a massive sandstone interval of northern Bida basin which constituted the study area and come up with four lithofacies; sand conglomerate facies, medium to coarse grained sandstone facies, siltstone facies and fine to medium grained sandstone facies displaying varying degrees of colour mottled.

1.2 **Geology of Bida basin**

The Bida basin is bounded to the north and south by the Precambrian basement rocks. The largest portion of the basin occurred at the southern half of Niger State, which formed the central portion of the basin that constitutes the study area (Figure 1.1).

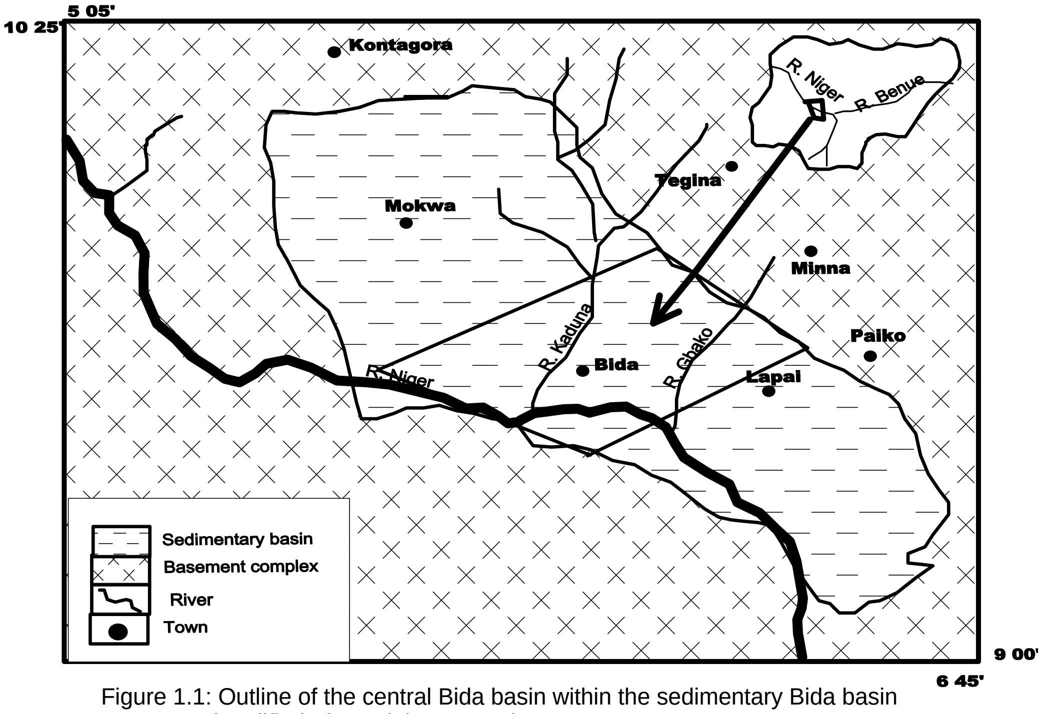


Figure 1.1: Outline of the central Bida basin within the sedimentary Bida basin (Modified after Adeleye, 1989).

The buried Precambrian basement complex is directly overlain by rounded to sub-rounded coarse conglomerates, clay-sand-pebble admixtures and cross- stratified sandstones locally with scattered pebbles, cobbles and boulders. The stratigraphy and sedimentation of the Upper Cretaceous (Campanian – Maastrichtian) succession of the Bida Basin have been study and documented by Adeleye and Dessauvagie (1972), in the central parts of the basin around Bida.

Four mapable stratigraphic units are recognizable in the area comprising the Bida Sandstone (including the Doko and Jima members), Sakpe Ironstone, Enagi Siltstone and Batati Ironstone Formations that were correlated with the stratigraphic units in the southern Bida Basin (Figure. 1.2).

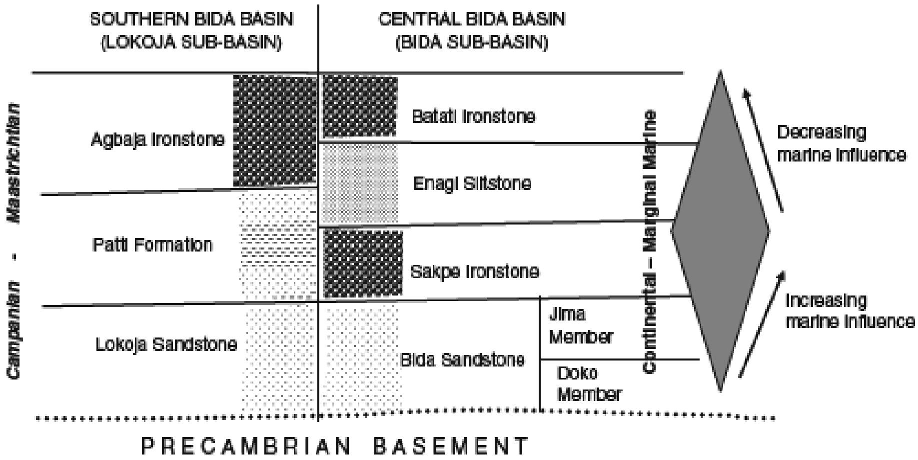


Figure 1.2: Stratigraphy of Bida Basin (Modified by Obaje, 2009 after Adeleye *et.al.*, 1972)

3 Materials and Methods

Clay samples were obtained from well exposed clay lithologic units of the formations, while pitting was adopted in grid pattern where there was poor exposure of clay. Sampling was done at

different vertical intervals using a hammer and plastic shovel. The geochemical analytical methods employ is Inductively Coupled Plasma mass spectrometer (ICP – MS) using Perkin-Elmer, Elan 6000 and inductively coupled plasma spectrograph on powdered, pressed pellets prepared from 3 – 5 g samples. X-ray Diffraction (X-RD) analysis was used to determine mineralogical composition of the clay sample using the new Empyrean PANalytical machine of D4674 (2011) model, powered by 45KV generator, and tube current of 40KV. The Xrays are diffracted by planes of atoms in the crystal structure and a patterns were produced, the diffraction patterns were recorded at scan range of 1-75 degree with a K-alpha 1 and K-alpha 2 radiations, and interpreted by database produce by XPert high score plus which comprises of Joint Committee on Powder Diffraction Standard (JCPDS), and Inorganic Crystal Structure Database (ICSD). The followings were also indentified, Name/Formula, crystallographic systems of the clay minerals found. The analysis was carried out in the geochemical laboratory of the Activation Laboratories limited (Actlabs) Ontario, Canada.

4 Results and Discussion

Field work revealed seven clay occurrences at different stratigraphic formations comprising of; Batati Ironstone Formation, Enagi Siltstone Formation, Sakpe Ironstone, and Bida Sandstone which were restricted to isolated hills in Nami, Gubaji, Lemu, Nakama, Batati, Kutigi, and Sapke ares, while Shegba and Kpaki are on floodplain and plain respectively (Figure 4.1). In hand specimen the clay varies between pure white and dirty white with occasional red/pink tint inherited from the overburden geological units. Most of the clays are occasionally laminated and gritty between fingers.

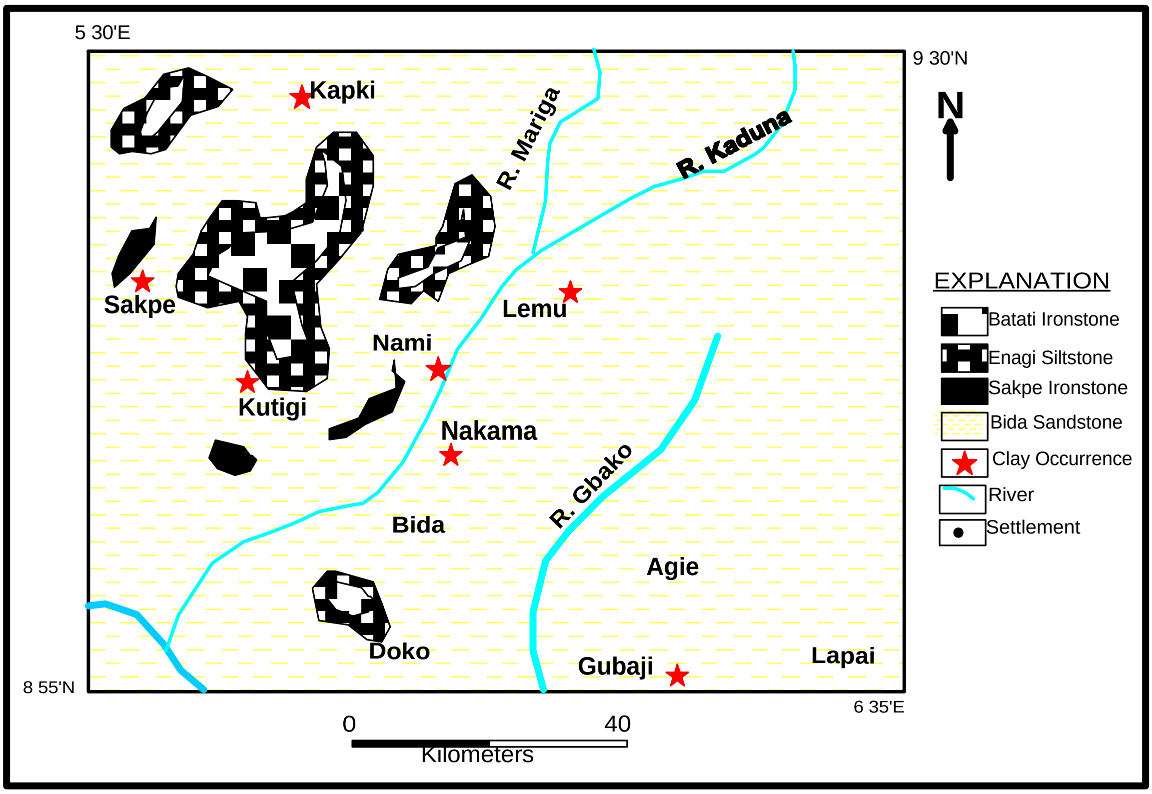


Figure 4.1: Geological Map of Central Bida Basin and Clay Occurrences

4.1 Batati Formation

4.1.1 Batati section (09 °10'N - 05 °45'E)

Along Batati – Danban road is exposed clay body of about 5 meters thick on an approximately 298 meters high hill above sea level with steep sides. The clay occurred beneath a bed of ironstone and lateritic clay, the basal unit of the hill is sandstone (Figure 4.2a). The hill is about 9 km to Dabban village off Bida – Batati road.

.3.1.2 Shegba section (09 °15'N - 05 °54'E)

Shegba village is about 20 km away from Batati village which is between Bida and Kutigi on Federal road. Clay occurrence in Shegba is within the alluvial plain of River Kaduna, the clay is grey in color with some mica flakes and generally sticky at hand. Field measurements from dug pits revealed 5 meters thick of clay bed which cover a relatively large area. The clay is presently worked for pot making by the native of Shegba (Figure 4.2b). To west of this location is a hill of about 15 m high composed of sandstone, lateritic soil and capped by ironstone.

3.1.3 Kutigi sections (09 °13'N - 05 °35'E and 09 °15'N - 05 °36'E)

Kutigi town host two hills containing clay, the first occurrence is located on a hill east of Kutigi village (Plate XXII). The basal unit of this hill is ferruginous sandstone overlain by lateritic clay. At the top of this unit is exposed clay bed of about 6 meters thick, overlain by laterite and capped by thin layer of oolitic ironstone (Figure 4.2c).

The second clay occurred on a hill west of Kutigi town of which a clay bed of about 3.5 meters is exposed in between laterite and capped sandstone (Figure 4.2d). The basal unit of this hill is sandstone. Both occurrences are white in color with red stains of laterite, and are about 1killometer apart.

3.2 Enagi Siltstone Formation

3.2.1 Kpaki sections (09 °20'N - 05 °32'E and 09 °22'N - 05 °32'E)

Kpaki host two clay occurrences, the occurrence are to west of Kapki village along Kpaki - Kodan road. The first occurrence is about 1 kilometer away from Kpaki village. About 8 meters clay bed is exposed from abandoned excavation and erosion surface, the clay is underlain by sandstone, and at the top of the clay is lateritic clay bed and capped by ferruginous sandstone (Figure 4.2e).

The second occurrence is about 2 m away and to east of the first occurrence. The clay measured about 6 m thick, underlain by feruginised sandstone and capped by thin layer of ferruginous sandstone (Figure 4.2f). These clay occurrences are pure white, fine and gritty in hand specimen and occurred on low land.

3.3 Sakpe Ironstone Formation

3.3.1 Sakpe section (09 °05'N - 05 °33'E)

At Sapke, clay occurred in two locations, the first location is to the east of SapkeA clay bed is poorly exposed at the top of oolitic ironstone and cap by thick overburden of laterite. The occurrence is poorly accessible, hilly and steep sided. The second location is to west of Sapke and about 2 kilometers away from the first location. A small clay body is well exposed on a hill with ferrugised sandstone base overlaid by about 3.5 meters laterite and capped by about 1.5 meters siltstone. The clay is very fine, pure white of about 5 meters thick and of area extent of about 1000 m^2 (Figure 4.2g).

3.4 Bida Sandstone Formation

3.4.1 Nami section (08 °40'N - 06 °30'E)

Nami hill is about 2 kilometers away from Nami village and 21 meters in height. It extended in northeast southwest direction. This section consists of massive reddish-brown sandstone at the lower part of the section, overlaying this unit is a bed of dirty white clay of average exposure thickness of 4 meters. The clay is overlay by laterite and capped by siltstone (Figure 4.2h).

3.4.2 Gubaji section (08 °56'N - 06 °10'E)

At Gubaji, a hill about 30 m high near Gubaji village contained a white clay bed at the top of a thick bed of lateritic soil. The whole section is capped by well sorted and friable ferruginised sandstone (Figure 4.2i). Field measurements from exposed clay body reveal about 5 meters laminated and sandy towards the top. The hill extended to about 1000 meters striking in NE – SW.

3.4.3 Lemu section (09 °22'N - 06 °03'E)

Lemu clay occurrence is on a hill east of Lemu town, the hill is underline by coarse grain sandstone, the sandstone is friable and contain matrix of breccias (Plate XXVII). At the top of the sandstone is an exposed clay bed of about 4.5 meters, sandy towards the top, followed by lateritic clay and capped by leteritic soil. In hand specimen the clay is greyish in color and grit feel at hand specimen (Figure 4.2j).

3.4.4 Nakama section (09 °10'N - 06 °04'E)

Nakama clay occurrence is about 50 kilomers to the south of Lemu village. The clay is exposed on a fairly high hill of about 350 m long, on Bida – Lemu road cut. The clay is capped by sandstone and underlain by lateritic clay and medium grained sandstone which is typical of Bida sandstone. The clay is white in color with purple tint, capped by about 1 m thick sandstone. In hand specimen the clay is very fine and silty (Figure 4.2k).

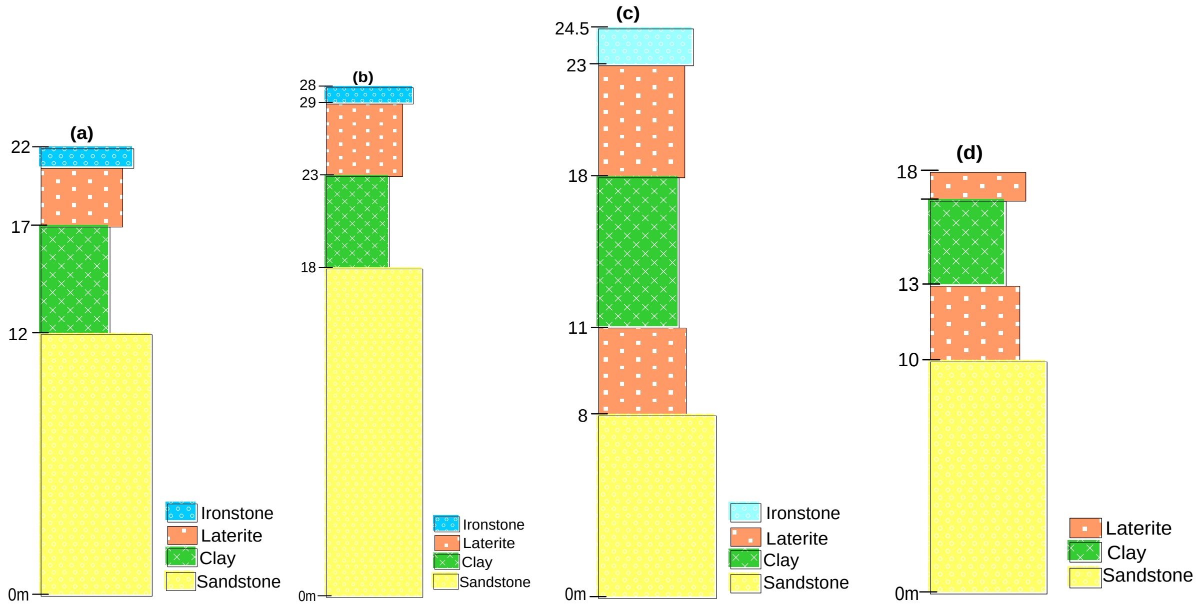
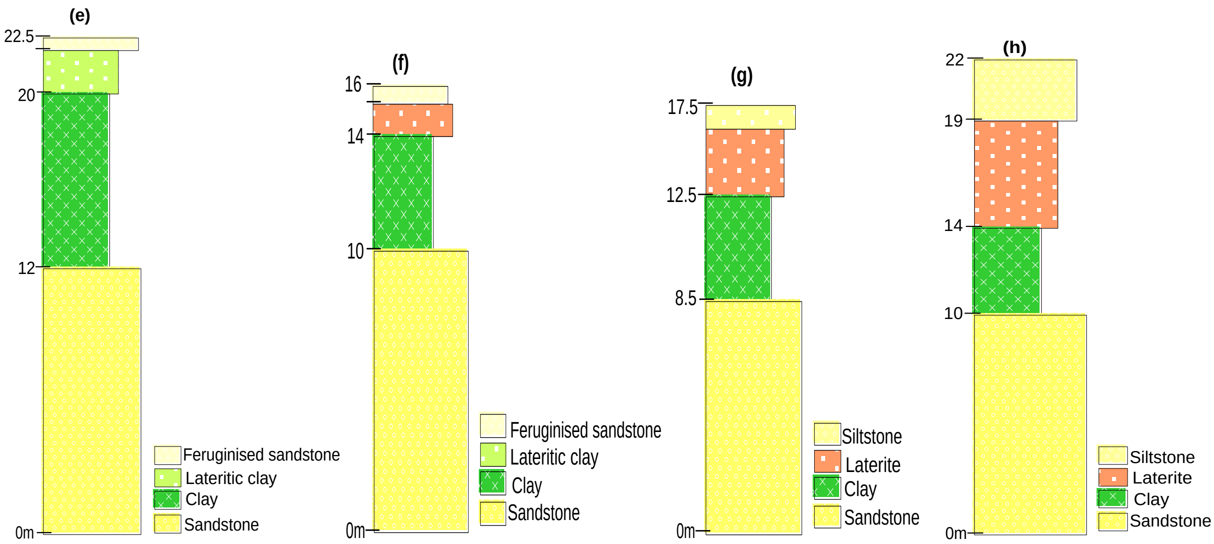
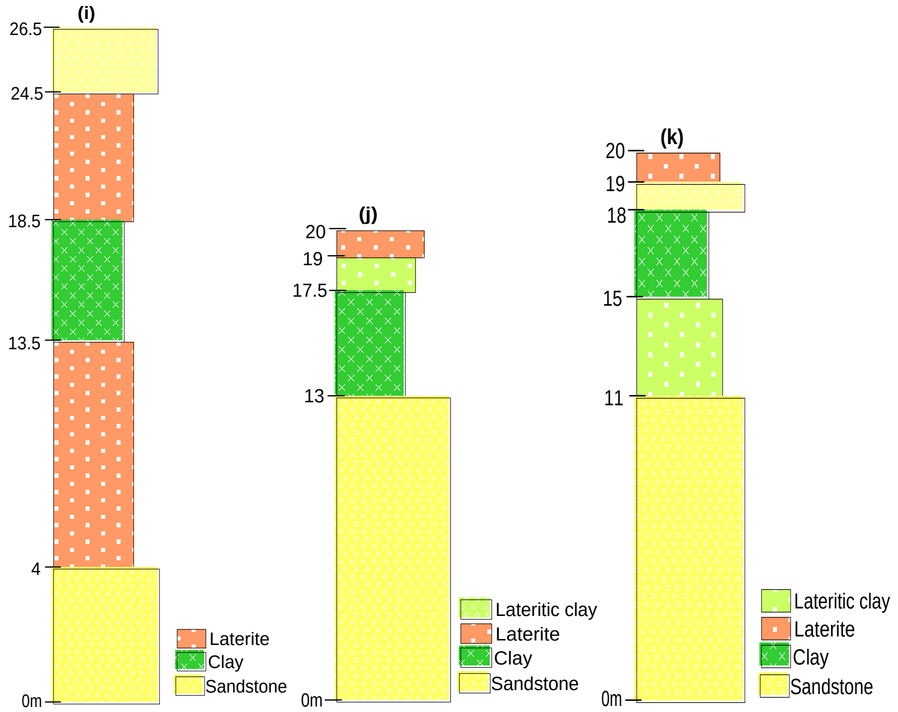


Figure 4.2: Vertical section of clay occurrences in the Centra Bida Basin: (a) Batati section (b)Shegba (c) Kutigi "A" (d) Kutigi "B"



(Figure 4.2) (e) Kpaki "A" section (f) Kpaki "B" section (g) Sakpe section (h) Nami section



(Figure 4.2) Gubaji section (j) Lemu section (k) Nakama section

4.2 Mineralogical analysis of clay samples

Result of the mineralogical analysis X-Ray Diffraction (X-RD) presented in Table 3.1. The mineralogical assemblage of all the samples have been indicated against their major diagnostic peaks. Generally, average mineral composition of Kaolinite account for 55% in clay mineral occurrence of Shegba, Sakpe, Kutigi, Nami, Batati and Kpaki while average quartz account for 40%, muscovite/illite and anatase average account for 5%. Nakama, Gubaji and Lemu occurrences have average mineral composition of Kaolinite 30%, quartz 65% and muscovite/illite and anatase 5% (Figure 4.3).

Table 4.1: Mineralogical Composition of Central Bida Basin Clay Samples

Location	Quartz	Kaolinite	Muscovite/Illite	Microcline	Anatase	Total %
Nami	42.4	55.0	1.9	n.d	0.7	100
Gubaji	61.5	33.4	4.6	n.d	0.4	99.9
Lemu	75.3	22.1	2.2	n.d	0.4	100
Nakama	65.1	28.1	6.3	n.d	0.5	100
Shegba	35.8	52.4	5.1	6.2	0.6	100.1
Batati	50.7	42.6	6.0	n.d	0.8	100.1
Kutigi 1	50.8	40.5	7.9	n.d	0.8	100
Kutigi 2	39.7	47.3	11.9	n.d	1.0	99.9
Sakpe	27.8	66.2	4.7	n.d	1.3	100
Kpaki	56.0	37.4	5.7	n.d	0.9	100

Shallow burial of clay minerals usually account for the formation of illite mineral during diagenesis of clay minerals in sedimentary basin. The presence of illite in trace amount confirmed shallow burial of the clay occurrences in the study area. Also, the poly-cyclic lithology of coarsed – fine – coarsed sediments revealed high – low energy of paleo-current during the deposition of sediments of which the clay beds generally represent the end of a depositional cycle.

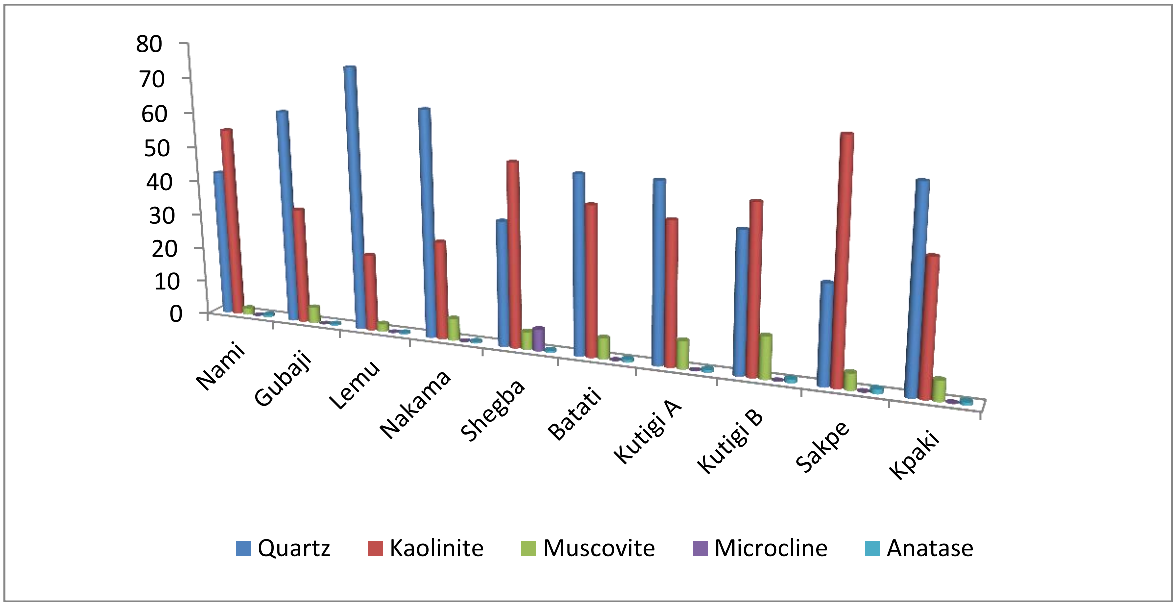


Figure 4.3: Average mineralogical composition of clay samples from central Bida basin

3.6 Chemical analysis of clay samples

The geochemical analysis result of thirty clay samples from the study area show high value of SiO_2 ranging between 54.91wt% and 87.37wt%, and moderately high Al_2O_3 ranging between 7.4wt% and 29.67wt%, and a low value of Fe_2O_3 ranging between 1.13wt% and 7.11wt%. However, the samples are low in CaO, Na_2O and K_2O except for Shegba clay which is slightly higher in K_2O (Table 4.2).

Table 4.2: Major Oxide distribution of central Bida basin clay samples

Location	SiO_2	$Al2O_3$	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LOl	Total
Nami 1	67.84	19.23	1.85	0.008	0.04	0.03	0.03	0.14	1.039	0.05	8.30	98.56
Nami 2	69.58	18.12	1.70	0.007	0.04	0.03	0.04	0.14	1.054	0.05	8.26	99.05
Nami 3	68.34	18.74	1.79	0.007	0.04	0.03	0.03	0.14	1.052	0.03	8.32	98.53
Gubaji 1	77.53	12.93	0.78	0.012	0.06	0.03	0.03	0.34	2.160	0.05	4.86	98.79
Gubaji 2	81.13	11.52	0.72	0.012	0.09	0.04	0.07	0.43	1.926	0.05	4.28	100.3
Gubaji 3	79.73	11.01	0.67	0.012	0.05	0.03	0.03	0.29	2.020	0.02	4.42	98.29
Lemu 1	85.16	7.63	1.13	0.010	0.10	0.12	0.04	0.14	0.863	0.02	3.56	98.78
Lemu 2	85.16	7.46	1.05	0.007	0.04	0.04	0.04	0.13	0.860	0.02	3.56	98.36
Lemu 3	87.37	7.55	1.06	0.007	0.04	0.04	0.04	0.13	0.879	0.01	3.65	100.8
Nakama 1	63.52	23.39	1.09	0.008	0.12	0.09	0.06	0.71	1.699	0.06	8.41	99.15
Nakama 2	70.11	19.65	1.17	0.010	0.10	0.09	0.09	0.75	1.548	0.04	7.43	101.0
Nakama 3	69.66	19.79	1.14	0.009	0.09	0.09	0.09	0.75	1.511	0.04	7.42	100.6
Shegba 1	57.98	18.70	7.11	0.079	0.66	0.30	0.23	1.74	0.967	0.03	11.95	99.74
Shegba 2	59.80	18.33	6.98	0.057	0.64	0.30	0.22	1.76	0.962	0.03	11.48	100.6
Shegba 3	58.84	18.93	7.04	0.080	0.66	0.30	0.23	1.76	1.004	0.03	11.84	100.7
Batati 1	66.88	21.70	1.12	0.009	0.09	0.08	0.09	0.72	1.610	0.06	8.44	100.8
Batati 2	64.28	22.32	1.14	0.009	0.10	0.08	0.08	0.69	1.673	0.07	8.40	98.84
Batati 3	70.43	19.23	1.19	0.009	0.09	0.09	0.08	0.77	1.525	0.05	7.37	100.8
Kutigi A1	67.29	19.92	1.14	0.009	0.10	0.09	0.09	0.75	1.553	0.06	7.33	98.34
Kutigi A2	67.63	20.27	1.18	0.009	0.12	0.09	0.10	0.76	1.616	0.04	7.39	99.21
Kutigi A3	69.19	19.68	1.13	0.009	0.09	0.09	0.11	0.79	1.538	0.05	7.38	100.1
Kutigi B1	63.02	23.06	1.12	0.009	0.09	0.08	0.11	0.76	1.715	0.06	8.54	98.56
Kutigi B2	66.73	21.96	1.12	0.009	0.09	0.08	0.08	0.72	1.663	0.06	8.43	100.9
Kutigi B3	64.92	21.81	1.09	0.008	0.10	0.08	0.09	0.70	1.629	0.04	8.41	98.90
Sakpe 1	54.91	29.15	0.97	0.007	0.05	0.07	0.05	0.30	1.764	0.05	11.37	98.68
Sakpe 2	55.83	29.36	0.96	0.007	0.05	0.07	0.06	0.31	1.874	0.05	11.31	99.88
Sakpe 3	55.71	29.67	0.92	0.006	0.05	0.07	0.05	0.31	1.793	0.05	11.36	99.99
Kpaki A1	72.42	17.13	0.94	0.010	0.08	0.03	0.10	0.53	1.822	0.04	6.40	99.51
Kpaki B1	73.06	15.91	1.36	0.011	0.10	0.05	0.09	0.58	1.833	0.03	5.77	98.80
Kpaki B2	74.86	15.60	1.32	0.011	0.09	0.06	0.10	0.58	1.830	0.04	5.72	100.2

The low content of Na_2O, MgO and Co suggested intensive weathering and destruction of feldspar during transportation.Thus, the slightly higher in K_2O of Shegba clay signaled relatively small concentration illite mineral. Low values of MgO and CaO thus show the source rock is not carbonate or dolomatic, however signaled felsic in the nature of the source rock. The observed low value of Fe_2O_3 is due to iron rich fluid movement from the overburden ironstone causing

Fe_2O_3 to be deposited along the profile and imposing tint red colouration on the underlain clay bed. TiO_2 is relatively immobile during weathering compared to other elements and is mainly concentrated in phyllosilicates (Condie *et al.*, 1992), it concentration in sedimentary rocks strongly represent the source rock to be felsic (McLennan *et al.*, 1993). The moderate concentration of TiO_2 in the study clay samples suggested felsic source. Although P_2O is low, it may be explained by the accessory minerals like Monazite in silicic source rock. Loss of ignition (LIO) is due to highest hydration stage of hydrolysis products and reflects the presence of clay that release water and CO_2 respectively.

Positive co-variation plots of SiO_2 with Al_2O_3 and TiO_2 suggest residue of these oxides as a result chemical weathering of felsic source rock (Figure 4.4a and b). However, Na and K contents are usually controlled by feldspar and thus moderately positive coveriation of SiO_2 with Na_2O and K_2O implies the destruction of plagioclase feldspar as a result of chemical weathering in the source rock (Figure 4.4c and d).). Also, Fe_2O_3, CaO, MnO and MgO are usually enriched in mafic rock, their negative co-variation with SiO_2 suggest the source rock to be of felsic character (Figure 4.4e and h).

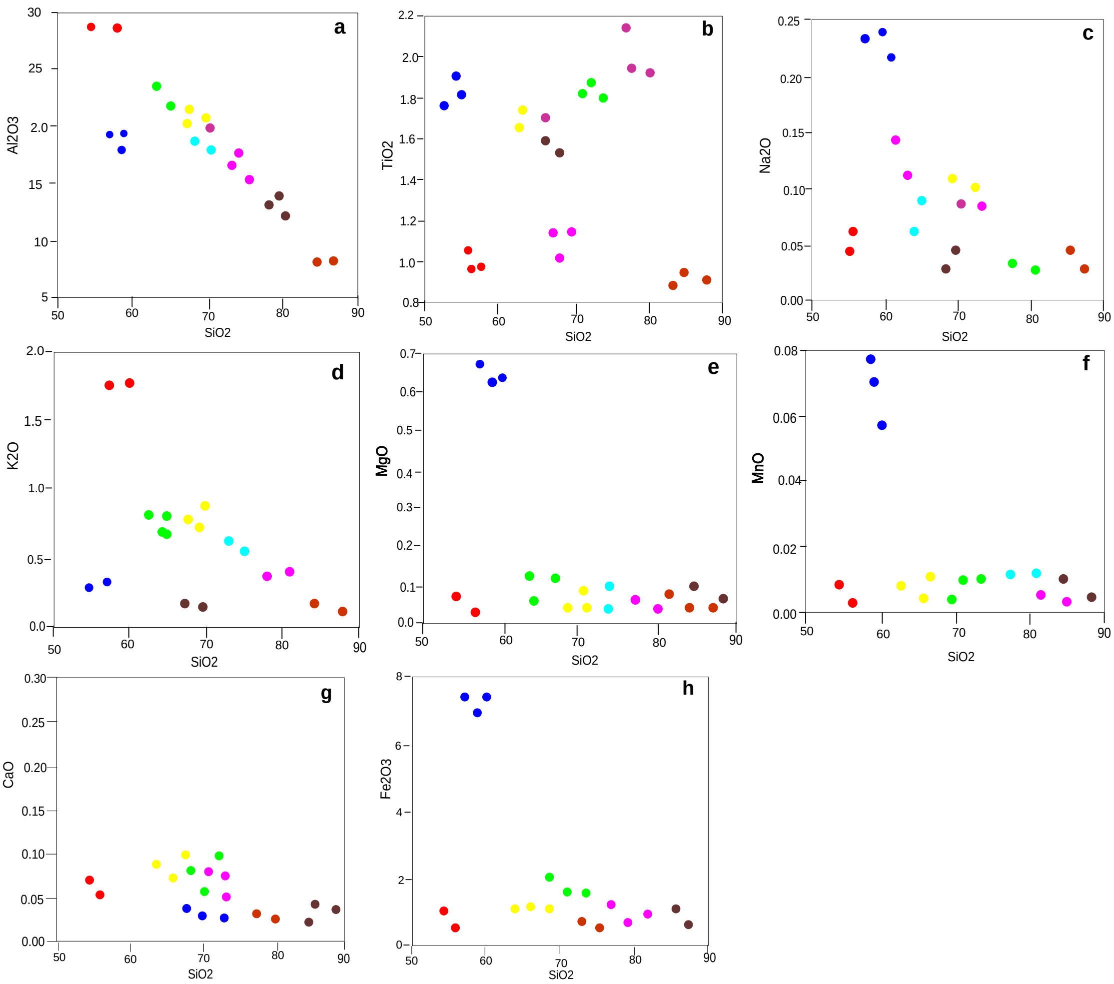


Figure 4.4: Co-variation plots of SiO_2 versus major elements of clay samples from Central Bida basin

Trace elements concentration of the study clay samples (Table 4.3), show all of the study samples have similar contents. High value of Th, Ba, Zr and moderately enriched value of Sc, V, Sr, Ga, Nb and Rb are shown, Be, Co and Cs are depleted in all the samples.

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Clay samples from the study area are quite enriched in Y, Zr, Nb, Th and U which is always associated with heavy minerals and resistance to weathering, these elements are enriched in felsic rocks rather than mafic rocks, which suggest the study clay to be of felsic provenance.

Table 4.3: Trace elements distribution of central Bida basin clay samples

Location Symbol	Sc	Be	V	Ba	Sr	Y	Zr	Cr	Co	Ga	Rb	Nb	Sn	Cs	Th	U
Nami 1	11	1	74	103	61	33	874	90	1	25	8	16	3	0.7	27.5	7.0
Nami 2	11	1	73	101	54	30	878	100	1	24	9	17	4	0.7	26.3	6.7
Nami 3	11	1	71	99	56	32	883	140	2	24	9	17	3	0.7	25.5	6.7
Gubaji 1	11	2	77	140	21	87	1967	110	3	20	11	45	16	0.6	28.3	11.5
Gubaji 2	11	2	72	117	18	89	1704	80	2	17	10	34	6	<0.5	29.0	11.0
Gubaji 3	11	2	70	118	16	88	2000	90	2	18	10	39	8	<0.5	27.6	10.7
Lemu 1	6	1	46	301	26	37	875	60	1	10	8	19	3	0.8	19.8	3.8
Lemu 2	6	1	44	105	16	39	839	50	1	10	8	14	3	0.8	18.7	3.9
Lemu 3	6	1	43	106	16	37	864	130	1	10	9	14	3	0.8	19.3	3.8
Nakama 1	15	2	87	230	36	41	919	110	6	31	25	28	5	0.9	34.5	6.0
Nakama 2	13	2	79	220	31	36	1023	90	5	27	25	27	5	0.8	31.6	5.5
Nakama 3	12	2	79	215	31	37	1046	90	5	27	25	24	5	0.7	30.7	5.5
Shegba 1	15	3	116	479	71	36	459	90	16	26	107	22	3	6.2	17.6	5.7
Shegba 2	15	3	111	451	75	37	485	120	14	26	108	23	3	6.1	18.6	5.8
Shegba 3	15	3	116	499	72	36	464	90	17	27	111	23	3	6.4	18.3	5.9
Batati 1	14	2	87	220	36	44	1163	100	6	29	24	33	6	0.9	35.5	6.3
Batati 2	14	2	82	213	33	45	1107	110	6	30	24	31	6	0.9	33.7	6.2
Batati 3	12	2	81	236	34	39	1170	130	5	27	25	31	5	0.8	33.3	5.9
Kutigi A1	12	2	77	214	31	39	1043	90	5	27	25	25	5	0.8	30.7	5.5
Kutigi A2	12	2	78	214	32	39	1044	130	5	28	25	26	5	0.8	31.8	5.6
Kutigi A3	12	2	81	216	34	38	1173	80	5	27	26	31	5	0.8	33.7	6.0
Kutigi B1	14	2	88	222	37	43	965	100	6	30	25	31	5	0.9	35.8	6.3
Kutigi B2	14	2	87	218	36	42	1087	150	6	30	24	31	5	0.9	36.7	6.6
Kutigi B3	14	2	83	216	33	39	1014	110	6	30	24	29	6	0.9	33.3	6.1
Sakpe 1	18	3	86	107	40	58	992	130	10	40	13	36	5	0.5	38.0	7.8
Sakpe 2	18	3	82	114	37	54	1017	150	10	39	13	35	6	0.6	33.1	6.9
Sakpe 3	18	3	85	107	39	55	993	130	9	38	12	36	5	0.5	36.3	7.2
Kpaki A1	13	1	73	179	25	46	1011	90	4	25	17	32	5	1.1	18.2	6.2
Kpaki B1	10	1	81	186	26	63	1247	110	4	22	17	23	4	0.9	19.0	6.1
Kpaki B2	10	2	79	185	26	62	1346	80	4	22	18	23	4	0.8	18.8	6.1

The results of the rare earth element analyses of clay samples have similar concentration of REEs. Chonderite-normalized patterns are typical for clay in general, with enrichment of LREEs (Figure 4.5). All samples show pronounced negative Eu anomalies ranging from 1.10 – 2.15 ppm.

In general, chondrite-normalized REE patterns display high light REE/heavy REE ratio between 2.34 and 19.511 (Table 4.4), flat HRE and negative Eu anomaly. The high light REE/heavy REE ratio and negative Eu anomaly suggest felsic source rocks, while low light REE/heavy REE ratio and no Eu anomaly mafic source rocks (Cullters and Graf, 1983). The studied clay samples are of high light REE/heavy REE ratio and negative Eu anomaly confirming felsic source rocks.

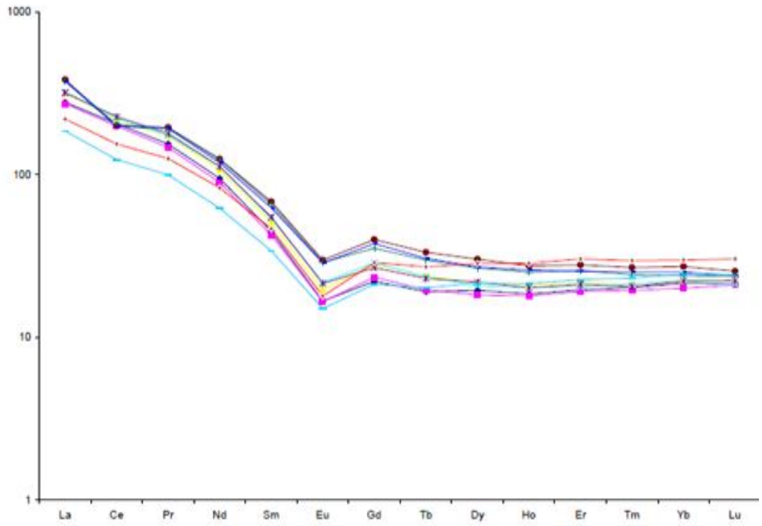

Figure 4.5: Chondrite normalized rare earth elements plot for central Bida basin Clay samples (after Taylor and McLenna, 1985)

4. Conclusion

Field work revealed seven Kaolin occurrences at different stratigraphic formations comprising of; Batati Ironstone Formation, Enagi Siltstone Formation, Sakpe Ironstone, and Bida Sandstone which were restricted to isolated hills in Nami, Gubaji, Lemu, Nakama, Batati, Kutigi, and Sapke ares, while Shegba and Kpaki are on floodplain and plain respectively of which their colour varies from pure white to milky white and in some locations tint red, presence of illite mineral is due to the Ilitization processes in the basin. Combined major oxides, trace elements and rare elements composition of the study clay samples suggest the provenance to be of felsic character.

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Table 4.4. Rare elements distribution of central Bida basin clay samples

Location	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	LREE	HREE	LREE/HREE	ΣREE
Nami 1	114	208	21.9	73.6	11.5	1.79	8.0	1.2	6.7	1.2	3.4	0.52	3.5	0.55	429	26.86	15.97	455.86
Nami 2	117	215	22.6	76.1	12.0	1.77	7.8	1.1	6.1	1.1	3.5	0.50	3.2	0.50	442.7	22.69	19.51	468.27
Nami 3	117	214	22.7	75.3	12.3	1.80	7.9	1.1	6.3	1.2	3.6	0.53	3.4	0.52	441.3	26.35	16.75	467.65
Gubaji 1	63.7	121	14.4	52.9	11.1	1.55	10.5	2.0	13.4	2.9	9.4	1.48	10.1	1.52	263.1	52.85	4.98	315.95
Gubaji 2	60.9	117	14.0	51.6	10.7	1.32	10.2	2.0	13.2	3.0	9.4	1.51	10.2	1.55	254.2	52.38	4.85	308.09
Gubaji 3	62.5	122	14.4	54.1	10.9	1.36	10.1	1.9	13.2	2.9	9.7	1.53	10.3	1.60	263.9	52.59	5.02	316.49
Lemu 1	60.8	118	13.1	48.1	8.5	1.51	6.5	1.0	6.0	1.2	3.8	0.56	3.7	0.55	248.5	24.82	10.01	273.32
Lemu 2	53.8	108	12.2	44.6	8.3	1.34	6.6	1.0	6.3	1.3	4.0	0.59	3.9	0.60	226.9	25.63	8.85	252.53
Lemu 3	55.9	111	12.5	46.0	8.7	1.42	6.7	1.1	6.5	1.3	4.0	0.58	3.8	0.61	234.1	35.96	6.51	270.06
Makama 1	106	192	20.8	69.4	10.5	1.57	6.8	1.1	6.5	1.3	4.2	0.63	4.1	0.66	398.7	26.86	14.84	425.56
Makama 2	86.0	165	17.1	56.3	8.4	1.16	5.5	0.9	5.7	1.2	3.8	0.61	3.9	0.63	332.8	34.26	9.71	367.06
Makama 3	84.3	160	16.4	53.7	8.0	1.19	5.4	0.9	5.9	1.2	4.0	0.64	4.2	0.64	322.4	14.21	22.69	336.61
Shegba 1	62.4	131	12.9	46.7	9.0	1.62	6.9	1.1	6.6	1.3	3.8	0.58	3.5	0.54	262	22.94	11.42	284.94
Shegba 2	62.6	115	13.0	48.4	9.2	1.75	7.4	1.1	6.7	1.3	4.0	0.59	3.9	0.57	248.2	27.31	9.09	275.51
Shegba 3	62.7	133	13.1	48.3	9.0	1.77	7.2	1.1	6.4	1.3	3.7	0.56	3.6	0.57	266.1	26.2	10.16	292.3
Batati 1	100	183	19.3	65.7	9.8	1.46	7.5	1.2	7.2	1.5	4.7	0.71	4.7	0.72	377.8	29.69	12.72	407.49
Batati 2	102	187	20.5	58.3	10.6	1.56	7.3	1.2	7.5	1.5	4.8	0.73	4.8	0.75	378.4	30.114	12.57	408.54
Batati 3	85.7	163	17.1	54.8	8.5	1.21	5.8	0.9	6.1	1.2	4.1	0.63	4.3	0.66	329.1	24.9	13.2	354
Kutigi A1	84.9	161	16.6	55.1	8.4	1.24	5.6	0.9	6.0	1.3	4.1	0.64	4.2	0.68	325.1	24.66	13.18	350.66
Kutigi A2	87.5	167	17.2	56.4	8.6	1.21	5.7	0.9	6.3	1.3	4.2	0.65	4.5	0.69	326.7	24.81	13.17	361.51
Kutigi A3	85.7	161	16.4	53.3	8.2	1.19	6.1	1.0	5.9	1.3	4.1	0.62	4.2	0.68	324.6	25.09	12.94	349.69
Kutigi B1	99.4	177	19.2	63.9	9.8	1.41	7.3	1.2	7.0	1.5	4.6	0.68	4.7	0.72	369.3	29.11	12.69	398.41
Kutigi B2	101	181	19.5	67.0	10.3	1.57	7.4	1.2	6.7	1.4	4.4	0.68	4.6	0.69	378.8	28.64	13.23	407.44
Kutigi B3	100	184	20.0	66.8	10.5	1.55	6.9	1.1	7.1	1.4	4.5	0.65	4.6	0.72	381.3	28.50	13.38	409.82
Sakpe 1	120	162	21.8	74.4	13.1	2.15	10.3	1.6	9.8	1.9	5.9	0.86	5.7	0.82	391.3	39.03	10.01	430.33
Sakpe 2	119	165	21.6	73.7	12.6	2.09	9.1	1.5	8.7	1.8	5.5	0.77	5.0	0.76	391.9	35.22	11.13	427.12
Sakpe 3	118	161	21.5	70.8	12.0	2.07	9.8	1.5	8.8	1.8	5.4	0.81	5.2	0.77	383.3	36.16	10.60	419.46
Kpaki A1	58.2	100	11.1	37.1	6.5	1.09	5.5	1.0	7.0	1.5	4.8	0.74	5.1	0.78	212.9	90.61	2.34	303.41
Kpaki B1	69.0	125	14.0	49.5	8.9	1.29	7.5	1.3	9.2	2.0	6.5	0.95	6.2	0.98	266.4	35.92	7.42	302.32
Kpaki B2	64.6	124	13.9	48.8	8.7	1.28	7.5	1.4	9.2	2.0	6.4	0.97	6.4	0.98	260	36.13	7.20	296.13
Average	85.4	143	17.0	76.3	12.6	1.86	8.55	1.4	9.6	1.9	5.9	0.89	5.76	0.98	324.4	32.5	11.20	357.9
PAAS	38.0	80.0	8.90	32.0	5.60	1.10	4.70	0.7	4.40	1.0	2.9	0.40	2.80	0.43	164.5	16.97	9.69	181.00
UCC	30.0	64.0	7.10	26.0	4.50	0.88	3.80	0.6	3.50	0.8	2.3	0.33	2.20	0.32	131.6	13.57	9.70	146.17