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Mineralogy and Geochemistry of Mud Rock Units of the Late Cretaceous Kanawa and Gulani Formations, Eastern Gongola Basin, North-Eastern Nigeria: Implications for Provenance Studies

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Abstract
The clay mineralolgy and geochemistry of the mud rock units of the Late Cretaceous Kanawa and Gulani formations in the eastern Gongola Basin were investigated with the sole aim of unravelling the provenance. The distinctive clay minerals and other accessories minerals identified from XRD analysis included; dioctahedral smectite, partially ordered and well ordered kaolinites, illite, and glauconite, palygorskite, sepiolite (found only in the glauconitic horizon) etc, and quartz, microcline, anatase, muscovite, phosphate, hematite etc, respectively. The elemental composition within the same mud rocks unit analysed using XRF revealed the presence of the following major elements: Al_2O_3, Fe_2O_3, SiO_2, K_2O, CaO and TiO_2 in virtually all samples and P_2O_5 in only two samples. Additionally, trace elements identified from some of the samples are; V_2O_5, Cr_2O_3, BaO, MoO_3 etc. The major elements are consistent with the chemical composition of the clay minerals and other non-clay minerals present. The presence of Illite or/and smectite, and well ordered kaolinite suggest intense climatic fluctuations between warm and dry, to hot and humid tropical condition. From the geochemical evaluation of the mudrock units within the Late Cretaceous Kanawa and Gulani formations shows that they were probably derived from mafic (basaltic) rocks.
Keywords: Late Cretaceous; Kanawa and Gulani formations; north-east Nigeria, intense climatic fluctuation between warm and dry- hot and humid; sourced from mafic (basaltic) rocks.

1.0 INTRODUCTION

The term provenance in sedimentary petrology include all factors associated with the generation of sediment, with specific target to unravelling the composition of the parent rocks as well as the physiography and climatic condition of the source area from where the sediment is sourced (Weltje and von Eynatten, 2004). Therefore, the ultimate goal of provenance studies is to deduce the characteristics of source areas from measurements of compositional and textural properties of sediments, supplemented by information from other lines of evidence (Pettijohn et al., 1987).

Suitable analytical approaches to sediment provenance therefore also depend on grain size (Weltje and von Eynatten, 2004). According to them, successful methods to analyse, sand-sized sediments may not be applicable to finer grained materials. Cobbles and boulders potentially allow application of the full range of analytical methods that are used to study the primary source rocks, because the original mineral paragenesis is preserved and can be used to estimate metamorphic pressure–temperature–time paths (e.g., Cuthbert 1991). But in the case of finer grained sediments, they often lost all paragenetic information due to decomposition into individual mineral grains, as well as chemical and/or mineralogical transformations (Weltje and von Eynatten, 2004).

Clays are phyllosilicate minerals produced majorly during chemical weathering processes. Clay mineralogy is considered to be a powerful tool for interpreting weathering conditions and palaeoclimate of source area (Chamley, 1989; Ruffell *et al*. 2002; and Sheldon & Tabor, 2009). According to Chamley (1989), clay minerals accumulated in modern or past marine environments are mainly inherited from landmasses that resulted from post weathering of primary rocks and pedogenesis. The type of clay mineral assemblages in modern sediments is intricately linked to the geodynamic context, the composition of weathered primary rocks, and lastly the intensity of hydrolysis during chemical weathering which is dependent on the climatic conditions (Biscaye, 1965; Chamley, 1989). In older sedimentary succession, it is very necessary to resolve the issue of sediment reworking, diagenesis, or authigenesis before utilizing clays as indicators for palaeoclimatic conditions, since they may transform the primary composition, and change the palaeoclimatic signal (Thiry, 2000).

According to Maurice (2000; page 99), clay minerals in sediment or sedimentary rocks have three origins: i) inherited (detrital ie have been formed in another area but still stable in their presence location), ii) neoformed (authigenic ie formed insitu as a result of precipitation from solution or formed from amorphous silicate material) and iii) transformed (modified ie by ion exchange or cathion rearrangement). According to him, in the study of mudrocks it is very necessary that the origin of clays have to be ascertained for any meaningful interpretations to be made in terms of provenance of sediments. This is so because, neoformed clays reflect the pore-fluid chemistry, degree of leaching and temperature that existed within the basin of deposition, whereas inherited clays will give information on the provenance of the deposit and probably the climate there (Maurice, 2000; page 99-100).

Provided that these effects are clearly resolved, clay minerals such as kaolinite and/or smectite may be successfully used as indicators of humid versus arid conditions for the Mesozoic period (Ruffell et al., 2002; Schnyder et al.,2006).

Many and possibly most of the clay minerals in modern and ancient environments are detrital (Maurice, 2000). According to him, the clay mineralogy of deltaic mudrocks will reflect the source-area geology and climate.

The geochemical signatures of clastic sediments have been applied in provenance studies (Condie *et al*., 1992; Cullers, 1995; Madhavaraju and Ramasamy, 2002; Armstrong-Altrin *et al*., 2004; Nagarajan *et al*., 2007).

The aim of this study therefore, is to determine the provenance of the mud rock units of the Kanawa and Gulani formations from geochemical and mineralogical data.

2.0 GEOLOGICAL FRAMEWORK OF THE STUDY AREA

The Benue Trough is the most investigated of all the Cretaceous sedimentary basins in Nigeria because of the controversies surrounding the nature of its origin as well as wealth of economic mineral deposits associated with it. The trough extends northeastward from the Niger Delta of the Equatorial Atlantic into the continental hinterland of Nigeria. This megastructure is approximately 1000 km long and 120-150 km wide, and lies within the Pan African mobile belt of West Africa (Guiraud, 1990). It contains up to 6000 m of Cretaceous to Tertiary sediments and associated volcanics.The origin Benue Trough is intricately linked directly to the opening of the South Atlantic Ocean and complex inter-plate movements. Regionally, the trough is part of an Early Cretaceous rift complex known as the West and Central African Rift System. Two models were initially proposed for the origin of the Benue Trough; the rift and the srike-slip models. Zaborski (1998) reviewed the two models proposed by previous workers and came to a conclusion that the origin of the Benue Trough is best regarded as the combination of rifting and strike-slip faulting.

Maluski *et al*. (1995) reported that the Mesozoic to Early Cenozoic magmatism accompanied the evolution of the Benue Trough, where in the northern (upper) Benue Trough the magmatism is characterized by transitional and transitional tholeiitic basalts, in addition acidic magmatism of peralkaline nature is also present; having the Mesozoic basalt being abundant than the rhyolites. These rocks occur as lava flows and dykes, with the basaltic flows directly overlying the Pan-Afican Basement (around Dunne and Gwol areas) or interbedded with Early Cretaceous syn rifts sedimentation (around Shani, Guburunde, Bima Hills areas). According to them the total thickness of the Basaltic pile varies from few metres to 200 m. They went further to described the relationships between basalts and other rock types around Burashika area; the basalts directly overlying rhyolitic flows and interbedded with coarse detrital volcanic conglomerates composed of rhyolitic blocks.

The trough is subdivided into three sectors; the lower (southern) Benue Trough, the middle (central) Benue Trough and the upper (northern) Benue Trough. The upper Benue Trough bifurcates into an E-W trending Yola arm that terminates eastwards against the Cameroun basement and a N-S trending Gongola Basin which is contiguous with the Chad Basin (Zaborski *et al*., 1998). Between these two arms is an area structurally characterized by four major NE-SW trending sinistral strike-slip faults, namely, the Gombe, Bima-Teli, Kaltungo and Burashika faults (Zaborski *et al*., 1998). In addition to these faults are basement inliers, with the Kaltungo inlier being the most prominent (Zaborski, 1998). This median zone was described as the partially exposed basement high forming the axis of the Benue Trough (Benkhelil, 1988; 1989). Other authors used other names e.g. Carter *et al*. (1963) termed it the “Zambuk Ridge”, Guiraud (1993) the “Wuyo-Kaltungo basement high” and Zaborski (1998) adopted the same name but with slight modification as “Wuyo-Kaltungo high”.

The stratigraphic succession in the Yola and Gongola branches are slightly different. Accounts of the former area were provided by Carter *et al.* (1963) and Allix (1983), and of the latter by Carter *et al.* (1963), later modified by Popoff *et al.* (1986) and Zaborski *et al.* (1998). Most recently, Hamidu *et al*. (2013) and Ayok *et al*. (2014) proposed modifications for the Upper Cretaceous lithostratigraphic successions of the western and eastern Gongola Basin, respectively (Table 1). In this study, the stratigraphic succession of the Early Cretaceous sediments of the Gongola Basin by Zaborki *et al*. (1998) is adopted, while for the Late Cretaceous sediments of the eastern Gongola Basin the one of Ayok *et al*. (2014) is adopted.

Table 1. Lithostratigraphic succession in the eastern Gongola Basin Compared with previous scheme proposed for the Gongola Basin (TG – Tulkuma Group, GS – Gombe Sandstone).

Zaborski et al. (1998) (Gongola Basin)		Hamidu et al.(2013) (western Gongola Basin)	Ayok et al.(2014) (eastern Gongola Basin)
	Neogene to Quaternary		Biu Basalts (& dolerite intrusions)
Kerri-Kerri Formation	Paleocene (at least in parts)	Kerri-Kerri Formation	
Gombe Sandstone	Maastrichtian	TG – GS: Duguri Member / Arowa Member	
Pindiga Formation – Fika Member	Campanian	TG – "Upper Fika Member"	
?unconformity?	Santonian		
Pindiga Formation – Fika Member	Coniacian	Pindiga Formation – "Lower Fika Member"	Pindiga Group – "lower Fika Member" (now eroded)
Pindiga Formation – Dumbulwa/Gulani/ Deba Fulani Member	Turonian – Upper, Middle	Pindiga Formation – Deba Fulani Member	Pindiga Group – Gulani Formation
Pindiga Formation – Kanawa Member	Turonian – Lower	Pindiga Formation – Kanawa Member	Pindiga Group – Kanawa Formation
Yolde Formation	Cenomanian	Yolde Formation	Yolde Formation
Bima Group – "Upper Bima Formation"	Albian	"Upper Bima Formation"	"Upper Bima Formation"
Bima Group – "Middle Bima Formation"	Aptian	"Middle Bima Formation"	"Middle Bima Formation"
Bima Group – "Lower Bima Formation"	pre-Aptian	"Lower Bima Formation"	"Lower Bima Formation"
+ + Crystalline basement + +	Precambrian		

Summarily the sedimentary-fill consists of Early Cretaceous continental clastics and a dominantly marine Late Cretaceous succession (Zaborski, 1998). According to Guiraud, (1990), the thickest sediments recorded in the Benue Trough were believed to have been deposited in rhomb grabens or pull-apart basins with sinistral strike-slip borders trending N40ºE to N70ºE ("Benue" trend) and normal borders striking N120º to N160ºE ("Chad" trend). The later sediments accumulated during a Late Cretaceous thermo-tectonic sag episode as a result of transgressive and regressive episodes, and the youngest Cretaceous deposits accumulated during a renewed phase of rifting (Zaborski, 1998). The location of study area occurs in the eastern Gongola Basin (see figs.1a & 1b).

The Kanawa Member was deposited during the Late Cenomanian to Early Turonian transgression that affected the entire Benue Trough and also the Saharan region to the north (Busson, 1972; Reyment, 1980; Meister *et al.,* 1992), while the Gulani Member is considered the product of a Middle Turonian regressive episode (Zaborski *et al*., 1988).

Ayok *et al*. (2014) upgraded both the Kanawa and Gulani members of the "Pindiga Formation" to formational status, while the Pindiga Formation was upgraded to group status.

The Gulani Formation was interpreted as mainly comprising small-scale Gilbert-type delta lobes (represented by large-scale tabular cross-bedded sandstones and granulestones) prograding over shallow sublittoral interbedded shales and sandstones, or over each other (Ayok and Zaborski, 2014).

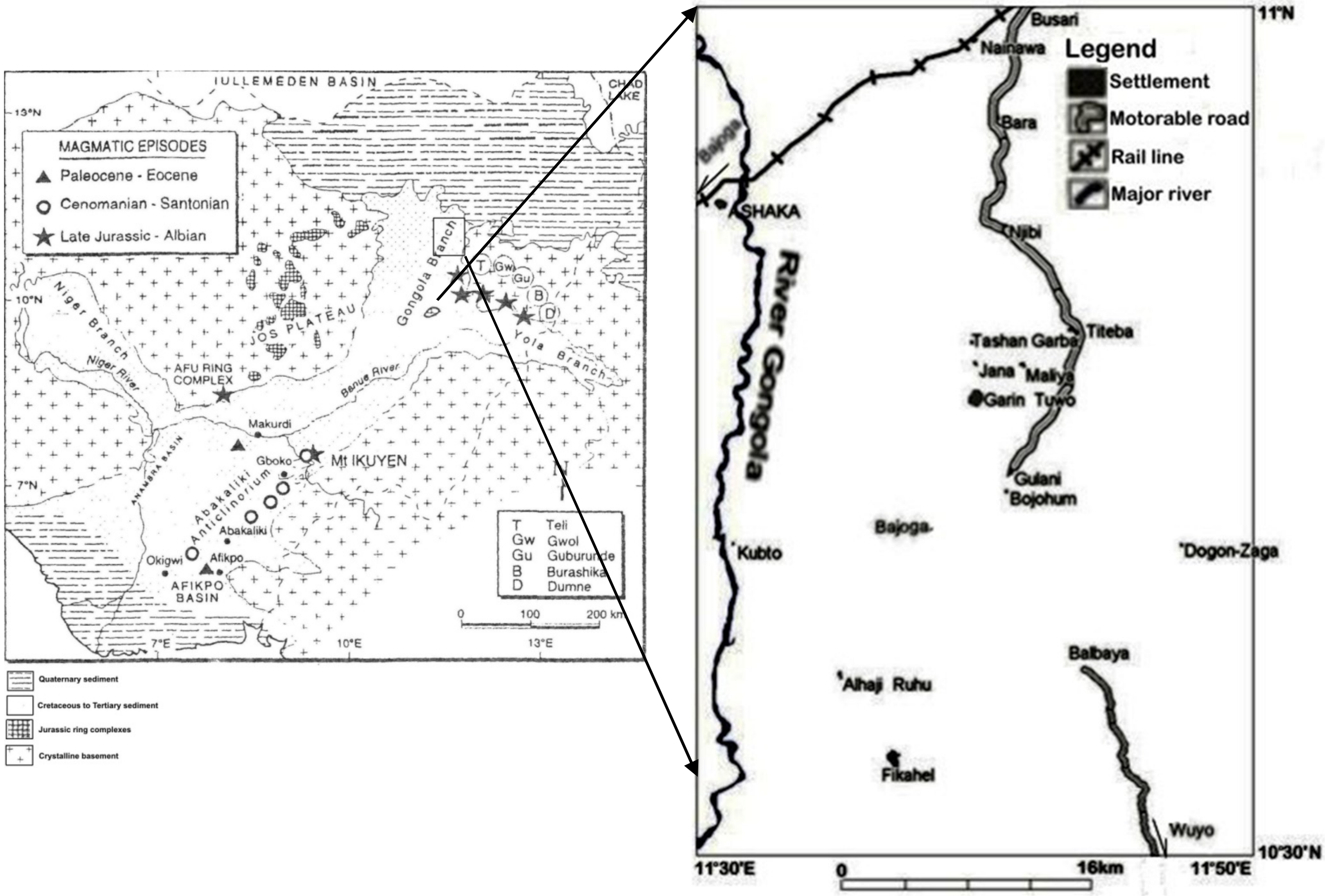

Figure 1a.Location of Mesozoic to Eocene volcanic episodes in the Benue Trough (Modified after Maluski *et al*. 1995; the blocked area represents the study area).

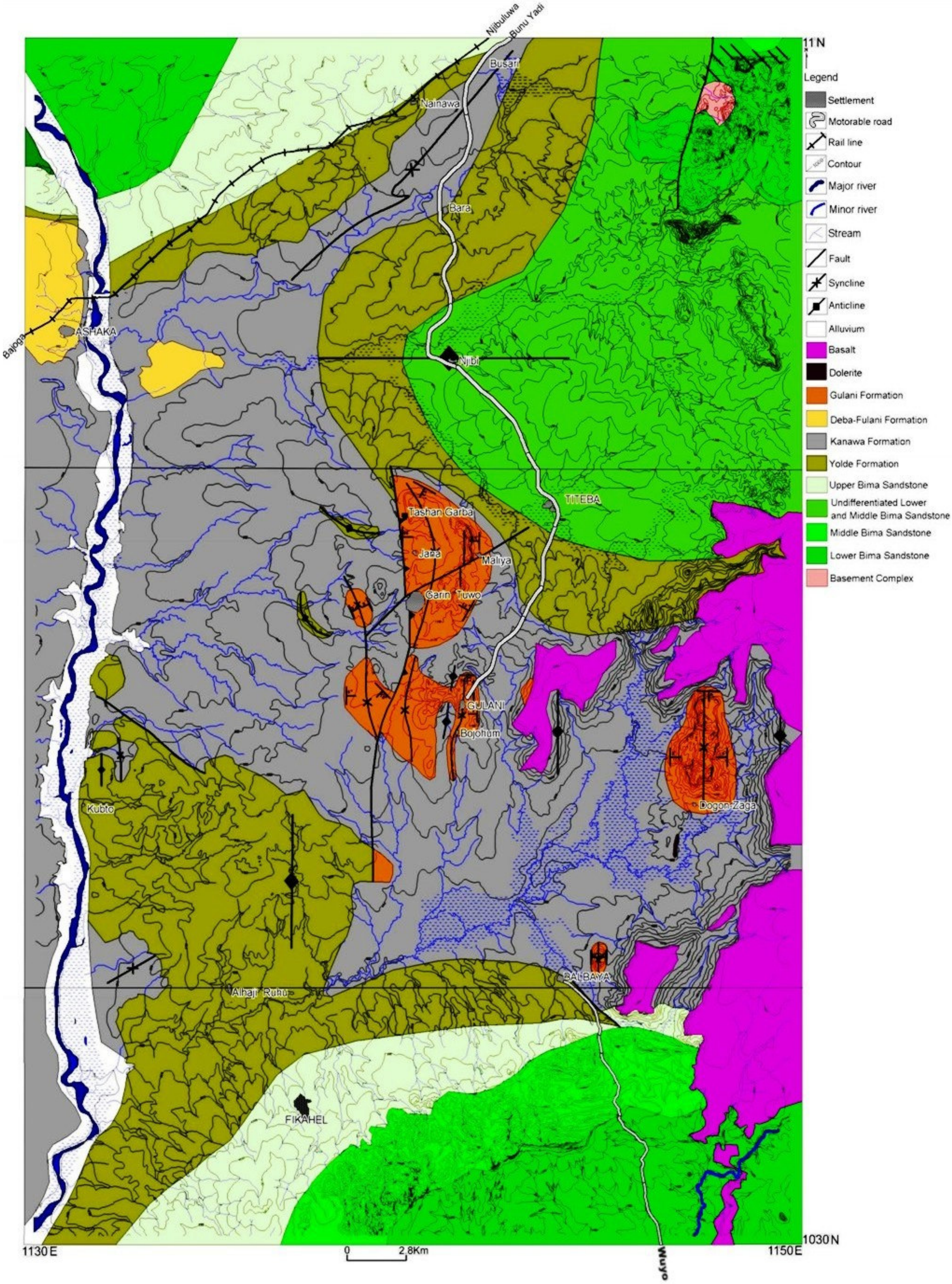

Figure 1b.The geological map of the study area (after Ayok *et al*. 2014)

3.0 METHODOLOGY

Detailed field mapping involving systematic logging technique of exposed sections was adopted and this included measuring thicknesses of beds with the help of a measuring tape, location of different lithofacies boundaries across/or along sections with the aid of Global Positioning System (GPS) technology and finally samples were collected for hand specimen description and laboratory analysis.

3.1 X-Ray Diffractometer (XRD) Analysis. A total of fifteen samples were obtained from the interbedded mudrock horizons and were subjected to XRD analysis in the laboratory of the Department of Earth Science, University of Silesia, Poland. Mineralogical phases were detected using a Philips pw 3710 X-ray diffractometer, and a computer program X'PERT and PDF 2data base.coKα1 radiation, graphitic intensity 30mA, time of counting impulse, 3, 9, 10 sec recording speed 0.01^{o} 2θ.

3.2 X-Ray Fluorescence (XRF) Analysis. A total of fifteen samples were obtained from the interbedded mudrocks horizons out of which fourteen samples (with the exception of the glauconitic horizon) were subjected to XRF analysis in the Laboratory of the Nigerian Geological Survey Agency, Kaduna. An X-Ray Spectrophotometer was used for the measurement of major and minor elements in their % oxide forms.

4.0 RESULTS

4.1 Lithologic description

The main study section is the type section of the Gulani Formation proposed by Ayok *et al*. (2014) and the detailed description is found therein, while an additional complimentary section of Ayok *et al*. (2014) north of Gulani is also considered. In the study type section the contact of the Gulani Formation (61 m thick) and the underlying Kanawa Formation (80 m thick) is transitional having a total thickness of 121 m (see figs. 2a & 2b). The bulk of the Kanawa Formation is made up dorminantly shale, with thin beds (less than a meter) of interbedded wackestones. The lower part of this unit consists of thin horizons of glauconitic rich clays. According to Ayok *et al*. (2014), the overlying Gulani Formation consist of a lower part comprising 'Kanawa Formation-type' shales and thin sandstones with *Thalassinoides* burrows interpreted as a sublittoral facies deposited on a ramp-like margin. The greater part of the Gulani Formation is made up of repetitive, coarsening-upward rhythms consisting of a similar but thinner subfacies (made of mudstone, siltstone, fine-grained sandstone) overlain by large-scale tabular cross-bedded, coarse-grained quartz arenite and granulestones. The other complimentary section is shown in figure 2c.

4.2 Mineralogical Composition of the Mudrock Units

The results of the X-Ray Diffractometer analysis is shown in table 2, and some of their respective diffractograms as well as their mineralogical interpretations are found in appendix 1. Below is the summary of the mineral phases present or probably present in all samples from the XRD analysis and include the following: Quartz (SiO_2); feldspars: $K[AlSi_3O_8]$-$Na[AlSi_3O_8]$; illite- $(K,H_3O^+)Al_2[AlSi_3O_{10}](OH)_2$; muscovite-$Al_2[AlSi_3O_{10}](OH)_2$; biotite-$(Mg,Fe,Mn)_3[AlSi_3O_{10}](OH)_2$,
Glauconite- $K_{0.66}Na_{0.06}Ca_{0.07}(Al_{0.46}Fe^{3+}{}_{0.99}Fe^{2+}{}_{0.18}Mg_{0.40}([Al_{0.31}Si_{3.69}O_{10}](OH)_2$,
smectite(montmorillonite)-$M_x(Al_{3.33}Mg_{0.67})[Si_8O_{20}](OH)_4.xH_2O$; beidellite-$M_x$ $Al_4[(Al_{0.67}Si_{7.33}O_{20}](OH)_4.xH_2O$; kaolinite-$Al_4[Si_4O_{10}](OH)_8$; palygorskite- $(Mg,Al)_5[Si_8O_{20}(OH)_2](OH_2)_4.4H_2O$ (?); sepiolite-$Mg_8[Si_{12}O_{30}](OH)_4(OH_2)_4$ $.8H_2O$ (?);
hematite- α-Fe_2O_3 (?); goethite- α-FeOOH; phosphates: crandallite ?- $CaAl_3[PO_4]_2(OH)_5$ $.H_2O$, goyazite ?- $SrAl_3[PO_4]_2(OH)_5$ $.H_2O$; phosphosiderite- $Fe^{3+}[PO_4].2H_2O$ (?); apatite- $Ca_5[(PO_4)_3|F,OH,CO_3,Cl]$ (?); amorphic substance (? volcanic glass).

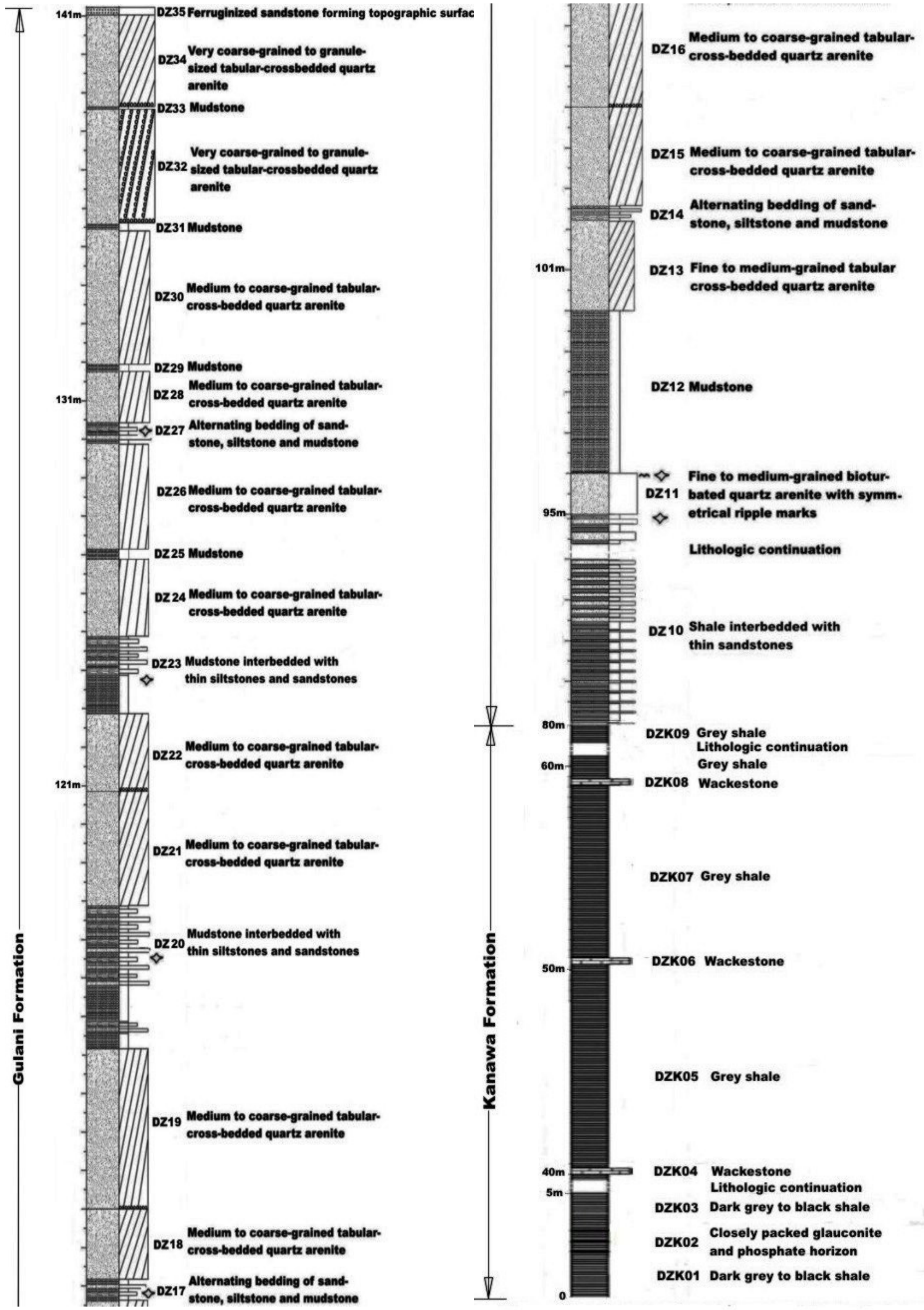

Figure 2: Lithologic Log of the type section of Gulani Formation at Dogon Zaga (After Ayok et al. 2014); a showing the upper part of log; b showing the lower part of log).

Table 2.Showing the various identified minerals present within the mud rocks of the Late Cretaceous Kanawa and Gulani formations (DZ are samples from the Gulani Formation type section while DZK are samples from the Kanawa Formation of the same section; G is sample from complimentary section of Gulani).

Sample No.	Quartz	K-Feldspar	Na-Feldspar	Kaolinite	Smectite (Montmorillonite)	Illite	Micas	Alumino-Phosphate Minerals	Other Minerals
DZ33	Major	Less		Major		Less	Less	Less of Crandallite?	
DZ31	Major	Less		Major		Less	Less	Less of Crandallite?	
DZ29	Major	Less		Major		Less	Less	Less of Crandallite-Goyazite?	
DZ27	Less			Major		Less	Less	Less of Crandallite-Goyazite?	
DZ25	Major			Major		Less	Less	Less of Crandallite?	
DZ23	Major			Major		Less		Less of Crandallite-Goyazite?	
DZ20	Major	Less		Major	Trace	Trace	Trace	Less of Goyazite?	Apatite, Hematite, Pho-sphosiderite
DZ17	Major			Major		Trace	Trace	Less of Crandallite-Goyazite?	Phosphosiderite, Hematite
DZ14	Major	Trace		Major	Trace	Less	Less	Less of Crandallite-Goyazite?	Phosphosiderite
DZ12	Major			Major	Trace	Less		Less of Crandallite?	
DZ10	Less	Less	Less	Less	Major	Less	Less		Amorphic substance (probably glass)
DZK09	Less	Less		Less	Major	Less	Less		Amorphic substance (probably glass)
DZK02	Less	Less		Trace	Major	Less		Rectorite, Palygosite, Glauconite?	Amorphic substance (probably glass)
DZKO1	Less	Less	Less	Less	Major			Less of Goyazite-Crandallite?	Amorphic substance (probably glass)
G12	Major	Less		Major		illite		Less of Goyazite-Crandallite?	

4.3 Geochemical Results of the Mudrock units

The results from the geochemical analysis are shown in table 3. The major, trace, rare earth elements are presented in weight percent and are use herein to confirm the presence or/and absence of some accessory minerals identified from X-Ray Diffractometer analysis, and also attempt to use the identified elements from the mud rock units within the Late Cretaceous Kanawa and Gulani formations to deduced the nature of the rocks and the likely paleo-weathering condition in the source area.

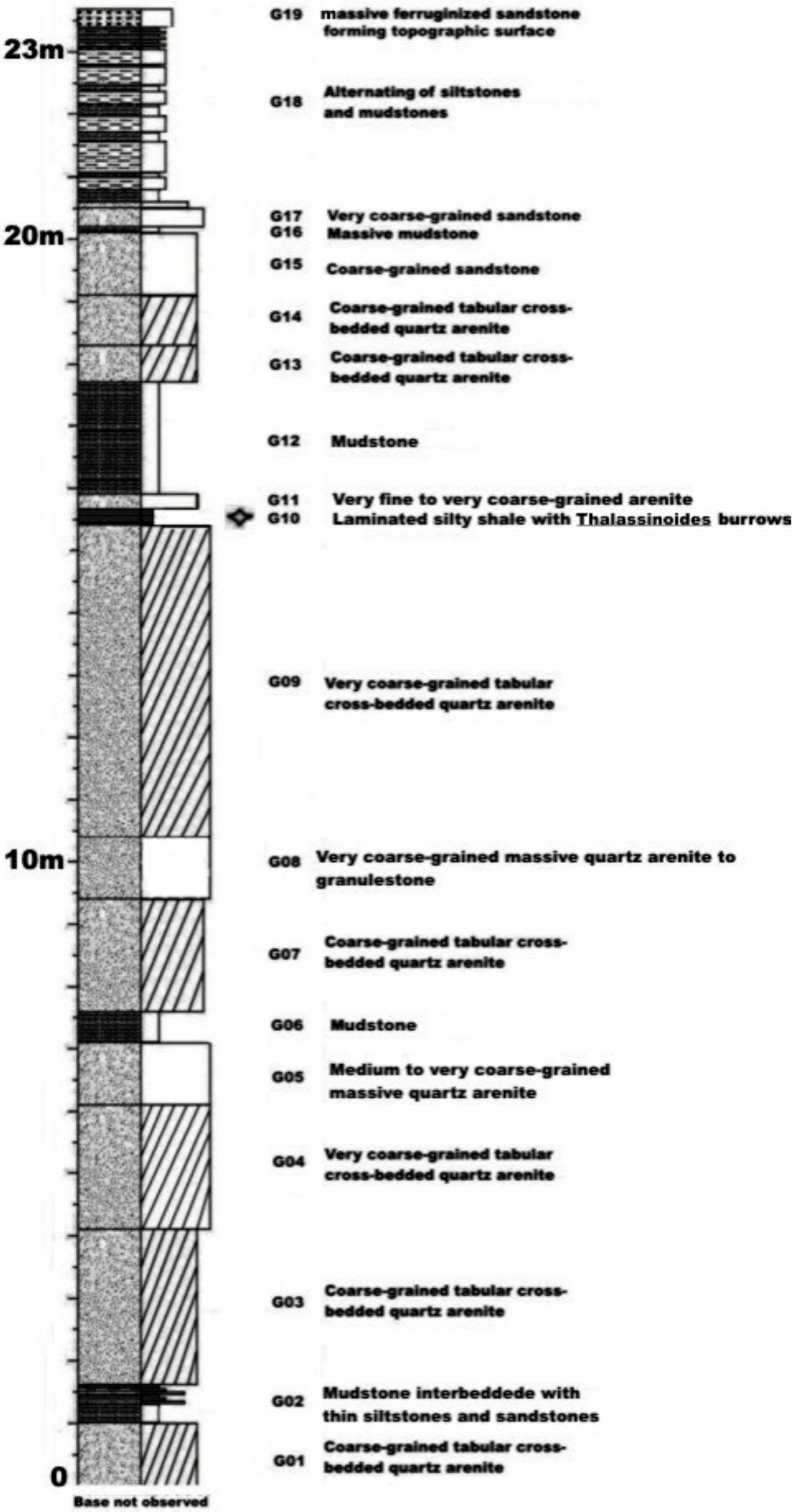

Figure 2c. Lithostratigraphic log of the Gulani Formation exposed 750 m north of Gulani (After Ayok *et al*., 2014)

Table 3. Showing the various identified major, trace and rare earth elements (in weight %; DZ are samples from the Gulani Formation type section while DZK are samples from the Kanawa Formation of the same section; G is sample from complimentary section of Gulani; nd-not detected).

Sample No.	Al_20_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	Cr_2O_3	V_2O_5	BaO	Eu_2O_3	Nd_2O_3	LOI	CIA	Al_20_3 / TiO_2
DZ33	14.00	nd	6.83	8.47	nd	nd	nd	nd	50.20	3.42	0.069	0.12	0.68	0.14	nd	8.90	62.31	4.0936
DZ31	25.00	0.30	1.37	0.14	nd	0.004	nd	0.54	55.1	5.99	0.082	0.24	nd	0.10	nd	10.70	98.27	18.519
DZ29	18.00	0.40	18.50	nd	nd	nd	nd	nd	44.20	6.28	0.10	0.27	nd	0.16	nd	9.30	97.83	2.8662
DZ27	16.00	nd	20.25	8.58	nd	0.01	nd	nd	44.90	1.62	0.02	0.03	0.42	nd	nd	7.60	65.09	2.8063
DZ25	15.00	0.22	35.56	nd	nd	nd	nd	nd	34.80	3.13	0.076	0.23	nd	nd	nd	10.90	98.55	4.7923
DZ23	17.00	nd	4.93	9.26	nd	0.006	nd	nd	58.00	2.55	0.033	0.071	0.61	0.05	nd	6.70	64.74	6.6667
DZ20	25.00	0.82	2.01	nd	nd	nd	nd	nd	38.90	15.20	0.30	0.51	nd	nd	nd	14.10	96.82	1.6447
DZ17	18.00	nd	6.70	7.40	nd	nd	nd	nd	54.80	2.36	0.030	0.084	0.51	0.13	nd	6.50	70.87	7.6271
DZ14	16.00	nd	4.05	10.10	nd	0.022	nd	nd	54.60	2.39	nd	0.100	0.79	nd	0.12	5.90	61.30	6.6946
DZ12	14.00	nd	6.27	9.76	nd	nd	nd	nd	51.60	2.70	0.047	0.076	0.80	nd	nd	8.20	58.92	5.1852
DZ10	15.00	1.54	21.20	6.71	nd	0.02	nd	nd	43.50	2.25	0.055	0.08	0.33	0.19	nd	8.90	64.52	6.6667
DZKO9	15.00	1.20	10.20	3.85	nd	0.049	nd	nd	47.70	2.52	0.063	0.13	0.26	0.27	nd	18.20	73.17	5.9524
DZK01	15.00	2.06	6.52	2.26	nd	0.15	nd	nd	51.40	2.70	0.054	0.13	0.24	0.20	0.11	18.40	77.64	5.5556
G12	19.00	2.91	5.93	nd	nd	nd	nd	1.20	49.40	4.26	0.089	0.17	1.30	0.13	nd	12.20	86.72	4.4600

5.0 DISCUSSION

The shale of the Kanawa Formation and the lower shale-dominated facies of the Gulani Formation have similar mineralogy; weakly ordered kaolinite and dioctahedral smectite with some isomorphic substitutions in octahedrons and different interlayer ions. These samples also contain amorphic substances, probably volcanic glass (which can alter to smectite) or mixed layered illite/smectite. The mudstone subfacies from the remainder of the bulk of the Gulani Formation indicates that they have mineralogical compositions with two main components; quartz and kaolinite, with accessory minerals (phosphates, micas, feldspars and probably Fe oxides) constituting up to twenty percent.

Most major elements are susceptible to post-depositional mobility and are of limited value for provenance analysis (Taylor and McLennan 1985; Clift *et al*. 2000; Armstrong-Altrin and Verma 2005). But according MacLean (1990), Pearce and Cann (1973) and Jenner (1996), Ti and Al may be relatively immobile up to greenschist-grade metamorphic conditions and because of that, their presence in clays of mudrocks are indicative of their detrital nature. Akinyemi *et a*l. (2013) reported that the positive correlation between TiO_2 and Al_2O_3 is suggestive of detrital nature of clay minerals. In this present study, the positive correlation between of TiO_2 and Al_2O_3 (with linear correlation coefficient of 0.64) is also indicative that the clay minerals are associated entirely with detrital phase.

Both kaolinite and smectite are form as a result of intense chemical weathering on land, and their association is, therefore interpreted as the end product of rock degradation in the hinterland and *in situ* weathering profiles (He and Liu, 1997). Smectite is generally believed to be produced during weathering in seasonally warm and dry climates with low water–rock ratio and low relief (Ruffell *et al*.2002; Fursich *et al*. 2005), while kaolinite abundance is a good indicator of landmasses with hot and humid (subtropical to tropical) climate supported by high water–rock ratio and well-drained, steep slopes (Chamley1989; Ruffell *et al*. 2002; Fursich *et al*. 2005; Bronger 2007; Sheldon & Tabor, 2009).

As presented in the XRD results (see table 2), the shales of the Kanawa Formation and lower portion of the Turonian Gulani Formation consists of majorly dioctahedral smectite with traces of weakly ordered kaolinite, suggesting that most part of the Late Cretaceous (Cenomanian to Early Turonian) was characterized by warm and dry climatic condition with low volume of water-rock ratio and low relief. The greater part of mudrock units within the Gulani Formation comprises of dominantly kaolinite and traces of smectite, indicating that most part of the Late Cretaceous (Middle Turonian) was characterized by wet and warmer climatic conditions with high volume of water-rock ratio, in well drained and steep slope, thereby promoting more of hydrolysis type of chemical weathering as revealed by absence or traces of Na, and traces/ minor amount of K from the geochemical results (see table 3). The humid/dry and warm climatic tropical conditions in the study area (eastern part of the upper/ northern portion of the Benue Trough) is a confirmation of similar kind of climatic condition during the Cretaceous in the southern Benue Trough as reported by Ikoro *et al*. (2012).

Accordingly, Yuretich *et al.* (1984) described that chemical weathering usually proceeds very rapidly under humid and warmer conditions with the removal of cations from feldspars through rapid leaching and subsequent formation of kaolinite. The near absence to low concentrations of elements such as Na and Mg in all the samples (see table 3) suggests that they were intensively leached as a result of intense chemical weathering in warm humid climatic conditions. Weathering causes the depletion of unstable minerals like feldspars and mafic minerals (e.g., pyroxene, amphibole, biotite), whereas comparatively stable minerals like quartz and zircon, as well as clay minerals, are enriched in the detrital spectrum.

The chemical index of alteration (CIA), a dimensionless number is defined as CIA= 100 x Al_2O_3/ (Al_2O_3 + CaO + Na_2O + K_2O) by Nesbitt and Young, (1982; 1984), and have been established as a general indicator of the degree of weathering in any source regions (Nesbitt and Young, 1982; Fedo *et al*. 1995). In the CIA formula, molar proportions are used, and CaO represent Ca in silicate minerals as opposed to phosphate and carbonate.

High values (i.e.76-100) indicate intensive chemical weathering at the source area whereas low values (i.e., 50 or less) indicate unweathered source areas.

CIA values for the shaly part of the Kanawa Formation and the lower shale portion of the Gulani Formation range between 64.52 to 77.64 (with an average of 71.78; see table 3) indicating moderate to intensive chemical weathering at the source area, while the remainder of mudrock units within the Gulani Formation have CIA values ranging from 58.92 to 98.27 (with an average of 78.31; see table 3) depicting intensive chemical weathering at the source area.

According to Hayashi *et al*. (1997), Al_2O3/TiO_2 ratio increases from 3 to 8 for mafic igneous rocks, 8 to 21 for intermediate rocks, and 21 to 70 for felsic igneous rocks. From the analysed mudrock samples, the Al_2O_3/TiO_2 ratio ranges from 5.5556 to 6.6667 (see table 2) for shales of the Kanawa Formation and lower portion of the Gulani Formation, suggesting that they were probably sourced from mafic igneous rocks, while the greater part of the remainder of mudrock units (mudstone, clayey siltstsone etc) within the Gulani Formation also were probably derived partly from a mafic igneous rocks as shown from the range of Al_2O_3/TiO_2 (1.6447 to 7.6271).

The presence of TiO_2 (illminite/or anatase) in shale subfacies of the Kanawa Formation and the lower part of the Gulani Formation, as well as the mudstone subfacies of the upper part of the Gulani Formation, is not surprising because it is a common heavy mineral in clays (Mahmut and Jackson, 1975). Anatase/or illiminite (TiO_2) is a common mineral in volcanic tuffs; its presence in mudrocks usually depicts a possible partially volcanic source.

According to Mclennan *et al*. (1993), the ferromagnesium trace elements such as Ni, Cr and V are generally abundant in mafic and ultramafic rocks therefore, their presence (especially Cr and V; see table 2) in some of the mudrocks may also be indicative of these rocks in the provenance area.

Maluski *et al*. (1995) described (both petrologically and geochemically) Mesozoic to Early Albian alkaline to tholeiitic basalt within the median/axial zone region of the northern (upper) Benue Trough (which is tens of kilometres away from the study area; see figure 1). Comparison of the mineralogical and geochemical compositions of these basaltic rocks and the mudrocks (see table 3) in the study area, suggest that the mudrocks were probably sourced from the basaltic rocks (mafic rocks).

6.0 CONCLUSION

The mineralogical composition of shaly subfacies of the Kanawa Formation and the lower shale-dominated facies of the Gulani Formation have similar mineralogy; weakly ordered kaolinite and dioctahedral smectite with some isomorphic substitutions in octahedrons and different interlayer ions. The glauconitic clay unit toward the bottom part of the Kanawa Formation contains similar mineralogical compositions to that of the shaly subfacies with additional minerals like glauconite, palygorskite, sepiolite. In the case of the mudstone subfacies from the remainder of the bulk of the Gulani Formation, the mineralogical composition comprises of two main components; quartz and kaolinite, with accessory minerals (phosphates, micas, feldspars and probably Fe oxides) constituting up to twenty percent.

The elemental composition within the same mud rocks unit comprises of the following major elements: Al_2O_3, Fe_2O_3, SiO_2, K_2O, CaO and TiO_2 in virtually all samples and P_2O_5 in only two samples. Additionally, trace elements identified from some of the samples are; V_2O_5, Cr_2O_3, BaO, MoO_3 etc. The major elements are consistent with the chemical composition of the clay minerals and other non-clay minerals present.

The presence of Illite or/and smectite, well ordered kaolinite suggest intense climatic fluctuation between warm and dry, to hot and humid tropical conditions.

From the geochemical evaluation of the mudrock units within the Late Cretaceous Kanawa and Gulani formations shows that they were probably derived from mafic (basaltic) rocks.

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REFERENCES

Akinyemi, S. A., Adebayo1, O. F., Ojo1, O. A., Fadipe, O. A. & Gitari, W. M. (2013). Mineralogy and Geochemical Appraisal of Paleo-Redox Indicators in Maastrichtian Outcrop Shales of Mamu Formation,Anambra Basin, Nigeria. *Journal of Natural Sciences Research*, Vol.3, No.10: 48-64.

Allix, P. (1983). Environments mésozoïques de la partie nord-orientale du fossé de la Bénoué (Nigéria). Stratigraphie, sédimentologie, évolution géodynamique. *Travaux laboratoire. Sciences Terre, Marseille St. Jérôme*, (B), 21: 1 – 200.

Armstrong-Altrin, J.S. & Verma, S.P. (2005). Critical evaluation of six tectonic setting discrimination diagrams using geochemical data of Neogene sediments from known tectonic settings: Sedimentary Geology, 177:

115–129.

Armstrong-Altrin, J. S., Lee, Y. I., Verma, S. P. & Ramasamy, S. (2004). Geochemistry of sandstones from the upper Miocene Kudankulam Formation, southern India: Implications for provenance, weathering, and tectonic setting. *Journal of Sedimentary Research*, 74(2): 285-297.

Ayok, J. Zaborski, P. M. Hamza. H. & Danbatta U.A. (2014). The Gulani Formation (Turonian) in the eastern Gongola Basin, north-east Nigeria: a re-evaluation of the lithostratigraphic status. *Journal of Mining and Geology*, 50 (1): 41-51.

Ayok, J. & Zaborski, P. M. (2014). Facies analysis within the Turonian Gulani Formation, eastern Gongola Basin, northeastern Nigeria. *African Geoscience Review*, 21: 79-87.

Benkhelil, J. (1988). Structure et évolution géodynamique du basin intracontinental de la Bénoué Nigria). *Bulletin de Centres des Recherches Exploration-Production Elf-Aquitaine*, 12: 29-128.

Benkhelil, J. (1989). The origin and evolution of the Cretaceous Benue Trough, Nigeria. *Journal of African Earth Sciences*, 8: 251 – 282.

Biscaye, P.E. (1965) Mineralogy of sedimentation of recent deep clay in the Atlantic Ocean and adjacent seas and oceans. *Geological Society American Bulletin*, vol.76: 803-832.

Bronger, A. (2007). Time dependence of the rate and direction of mineral weathering and clay mineral formation with special consideration to kaolinites. *Revista Mexicana de Ciencia Geológicas* 24: 510–523.

Busson, G. (1972). Principes, méthods et résultants d'une étude stratigraphique du Mésozoïque saharien. *Mémoir Museum National a'Histoire naturelle* (Paris) (n.s.), 26: 1-441.

Carter, J. D; Barber, W; Tait, E. A. & Jones, G. P. (1963). The geology of Parts of Adamawa, Bauchi and Borno Provinces in North-eastern Nigeria. *Bulletin of the Geological Survey of Nigeria*, 30: 1 – 108.

Chamley, H. (1989). *Clay Sedimentology*. Springer Verlag, Berlin, NewYork.

Clift, P.D., Degnan, P.J., Hannigan, R., & Blusztajn, J. (2000). Sedimentary and geochemical evolution of the Dras forearc basin, Indus suture, Ladakh Himalaya,India: *Geological Society of America, Bulletin*, 112: 450–466.

Condie, K.C., Boryta, M.D., Liu, J. & Quian, X. (1992). The origin of khondalites: geochemical evidence from the Archean to Early Proterozoic granulitic belt in the North China Craton. *Precambrian Research*, 59(3-4): 207-223.

Cullers, R. L. (1995). The controls on the major and trace element variation of shales, siltstones and sandstones of Pennsylvanian – Permian age from uplifted continental blocks in Colorado to platform sediment in Kansas,USA. *Geochimica et Cosmochimica Acta*, 58(22): 4955-4972.

Cuthbert, S.J., (1991). Evolution of the Devonian Hornelen basin, west Norway: new constraints from petrological studies of metamorphic clasts. In: Morton, A.C., Todd, S.P., Haughton, P.D.W. (Eds.), Developments in Sedimentary Provenance Studies. Geological Society of London Special Publication. 57: 343– 360.

Fedo, C. M., Nesbitt, H. W. & Young, G. M. (1995). Unravelling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering condition and provenance. *Geology*, 23: 921-924.

Fursich, F.T., Singh, I.B., Joachimski, M., Krumm, S., Schlirf, M. & Schlirf, S. (2005). Palaeoclimate reconstructions of the Middle Jurassic of Kachchh (western India): an integrated approach based on palaeoecological, oxygen isotopic, and clay mineralogical data. *Palaeogeography, Palaeoclimatology, Palaeoecology* 217, 289–309.

Guiraud, M. (1990). Tectono-sedimentary framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough, (NE) Nigeria). *Journal of African Earth Science*, 10: 341 – 353.

Guiraud, M. (1993). Late Jurassic rifting-Early Cretaceous rifting and Late Cretaceous transpressional inversion in the Upper Benue Basin (NE Nigeria). *Bulletin, Centres desRecherches Exploration-Production Elf-Aquitaine*, 17: 371-383.

Hamidu, I. Zaborski, P. M. & Hamza. H. (2013). A review of the Campanian to Maastrichtian lithostratigraphic succession in the Cretaceous Gongola Basin of north-east Nigeria. *Journal of Mining and Geology*, 49 (2):145-160.

Hayashi, K., Fujisawa, H., Holland, H. & Ohmoto, H. (1997). Geochemistry of ~1.9 Ga sedimentary rocks from northeastern Labrador, Canada. *Geochimica et Cosmochimica Acta*, 61(19): 4115-4137.

He, L. and Liu, Q. (1997). Chemical characteristics of clay minerals in the sediments from Yellow River and the Changjiang River. *Chinese Science Bulletin*, 42 (6): 488-492.

Ikoro D. O., Agumanu A.E. & Okereke C. N. (2012). Tectonic and paleoenvironmental significance of clay mineral suites in the southern Benue Brough. *International Journal of Emerging trends in Engineering and Development*, 2: 1-16.

Jenner, G.A., (1996). Trace element geochemistry of igneous rocks: geochemical nomenclature and analytical geochemistry, in Wyman, D.A., ed., Trace Element Geochemistry of Volcanic Rocks: Applications for Massive Sulphide Exploration: Geological Association of Canada, Short Course Notes, 12: 55–71.

Madhavaraju, J. & Ramasamy, S. (2002). Petrography and geochemistry of Late Maastrichtian - Early Paleocene sediments of Tiruchirapalli Cretaceous, Tamil Nadu - Paleoweathering and provenance implications. *Journal of the Geological Society of India*, 59: 133-142.

Mahmut, S. & Jackson, M.L. (1975). Anatase and rutile determination in kaolinite deposits *Clays and Clay Mineralogy*, 23: 437-443.

Maurice, E.T. (2000). *Sedimentary Petrology*. (third edition), Blackwell Oxford. 262 pp.

Maluski, H., Coulon, C., Popoff, M. & Baudin, P. (1995). Ar/Ar chronology, petrology and geodynamic setting of Mesozoic to early Cenozoic magmatism from the Benue Trough, Nigeria. Journal of the Geological Society, London, 152: 311-326.

Maclean, W.H., (1990). Mass change calculations in altered rock series: *Mineralium Deposita*, 25: 44–49.

Mclennan, S.M., Hemming, S., McDaniel, D.K. & Hanson, G.N. (1993). Geochemical approaches to sedimentation, provenance, and tectonics. *Geological Society of America Special paper*, 284: 21-41.

Meister, C., Alzouma, K., Lang, J. & Mathey, B. (1992). Les ammonites du Niger (Afrique occidentale) et la transgression transsaharienne au cours du Cénomanian-Turonien. *Geobios* 25: 55-100.

Nagarajan, R., Madhavaraju, J., Nagendra1, R., Armstrong-Altrin, J. S. & Moutte, J. (2007). Geochemistry of Neoproterozoic shales of the Rabanpalli Formation, Bhima Basin, Northern Karnataka, southern India:implications for provenance and paleoredox conditions. *Revista Mexicana de Ciencias Geológicas*, 24 (2): 150-160.

Nesbitt, H.W. & Young, G. M. (1982). Early Proterozoic climates and plate motions inferred from major elementchemistry of lutites. *Nature*, 299: 715-717.

Nesbitt, H.W. & Young, G. M. (1984). Prediction of some weathering trends of plutonic and volcanic rocks based thermodynamic and kinetic considerations. *Geochemica et Cosmochimica Acta*, 48: 1523-1534.

Pearce, J.A., & Cann, J.R. (1973). Tectonic setting of basic volcanic rocks determined using trace element analyses: Earth and Planetary Science Letters, v. 19, p. 290–300.

Pettijohn, F. J., Potter, P. E. & Siever, R. (1987). *Sand and Sandstone*, (*2nd edition*). Springer, New York. 553 pp.

Popoff, M, Wiedmann, J. & Wasz, I. (1986). The Upper Cretaceous Gongila and Pindiga Formations, Northern Nigeria. Subdivisions, age, stratigraphic correlations and paleogeographic implications. *Eclogae Geologicae Helvetiae*, 79: 343 – 363.

Reyment, R. A. (1980). Biogeography of the Saharan Cretaceous and Paleocene epicontinental transgressions. *Cretaceous Research*, 1: 299-327.

Ruffell, A., McKinley, J.M. & Worden, R.H. (2002). Comparison of clay mineral stratigraphy to other proxy palaeoclimate indicators in the Mesozoic of NW Europe. *Philosophical Transactions of the Royal Society, London A* 360: 675–693.

Schnyder, J., Ruffell, A., Deconinck, J.F. & Baudin, F. (2006) Cojuntive use of spectral gamma –ray logs and clay minerals in drilling Late Jurassicearly Cretaceous paleoclimate change (Dorset, U.K.), Paleo. Paleo. Paleo., 229: 303-320.

Sheldon, N.D. & Tabor, N.J., (2009), Quantitative paleoenvironmental and paleoclimatic reconstruction using paleosols: Earth-Science Reviews, 95: 1–52.

Taylor, S.R. & Mclennan, S.M. (1985).The Continental Crust: Its Composition and Evolution: Oxford, U.K., Blackwell, 312 p.

Thiry, M. (2000). Palaeoclimatic interpretation of clay minerals in marine deposits: an outlook from the continental origin.*Earth-Science Reviews* 49: 201–221.

Weltje G. J. & von Eynatten H. (2004). Quantitative provenance analysis of sediments: a review and outlook. *Sedimentary Geology*, 171: 1 – 11.

Yuretich, R.F., Hickey, L.J., Gregson, B.P. & Hsia, Y.L. (1984). Lacustrine deposits in the Paleocene Fort Union Formation, northern Bighorn Basin, Montana. *Journal of Sedimentary Petrology*, 54: 836-854.

Zaborski, P. M. (1998). A review of the Cretaceous System in Nigeria. *Africa Geoscience Review*, 5: 385 – 483.

Zaborski, P. M., Ugodulunwa, F., Idornigie, A., Nnabo, P. & Ibe, K. (1998). Stratigraphy and Structure of the Cretaceous Gongola Basin, northeast Nigeria. *Bulletin de Centres des Recherches Exploration Production Elf-Aquitaine*, 21: 153 – 186.

Appendix 1.

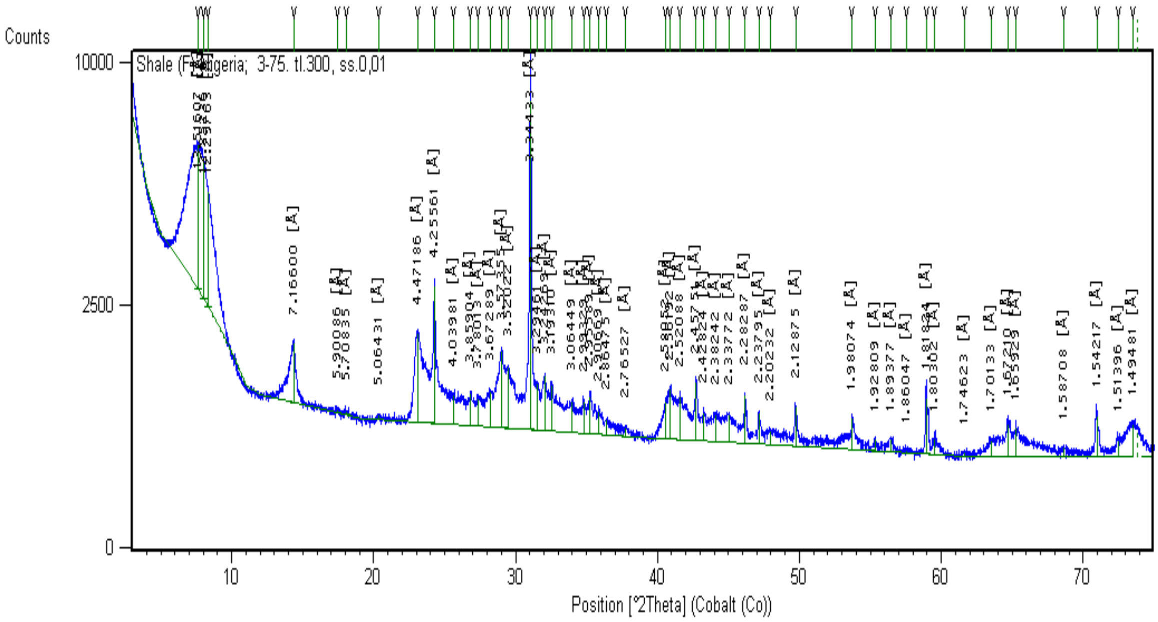

Figure 3. X-ray diffractogram showing clay and other accessory minerals of DZK01 in figure 2a (Macroscopically it is black, soft shale: The main mineral is dioctaedral smectite with a complicated composition Ca-Mg-Al-Fe. Additionally, quartz, weakly ordered kaolinite, K- and Na-feldspars, phosphate (goyazite, and crandallite) and glass are also present.

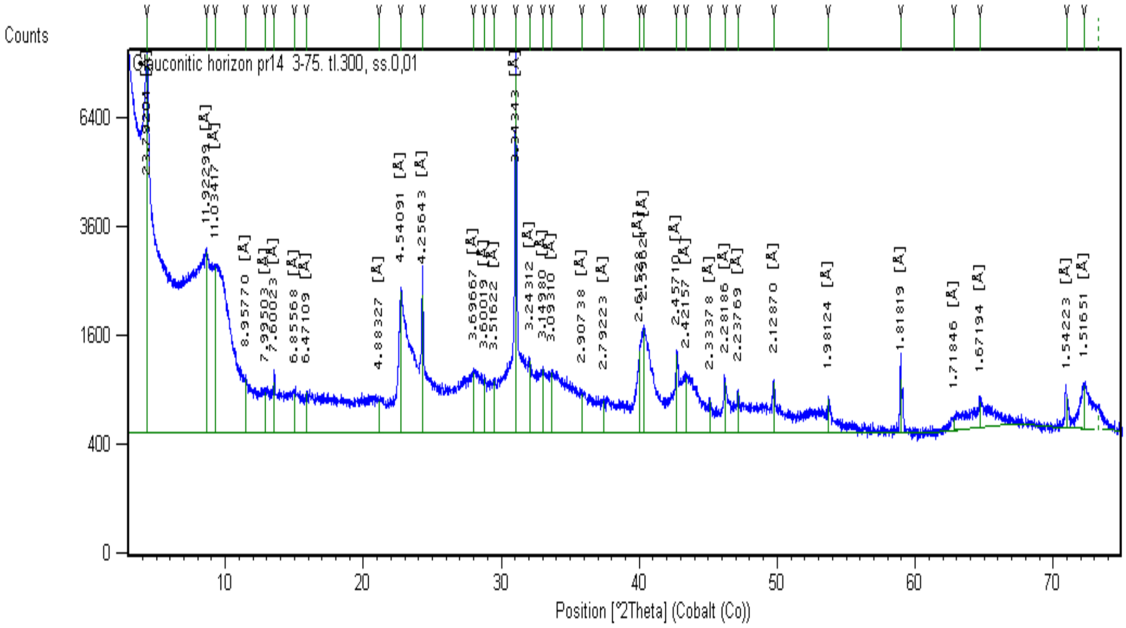

Figure 4. Zaga. X-ray diffractogram showing clay and other accessory minerals of DZK02 in figure 2a (Greenish-brown porous sample with rusty and beige blooms: Mineralogical composition is complex and difficult to establish. Additional treatment of the sediment was necessary to help in mineral identification. It consists mainly of clay minerals: regular mixed-layered structure illite/smectite (called rectorite), montmorillonite (close to beidellite), glauconite probably with some swelling layers of smectite, quartz, probably palygorskite ? and/or sepiolite, K-feldspar, illite, traces of kaolinite and weakly crystallized Fe minerals. Amorphic substance (glass) is also present.

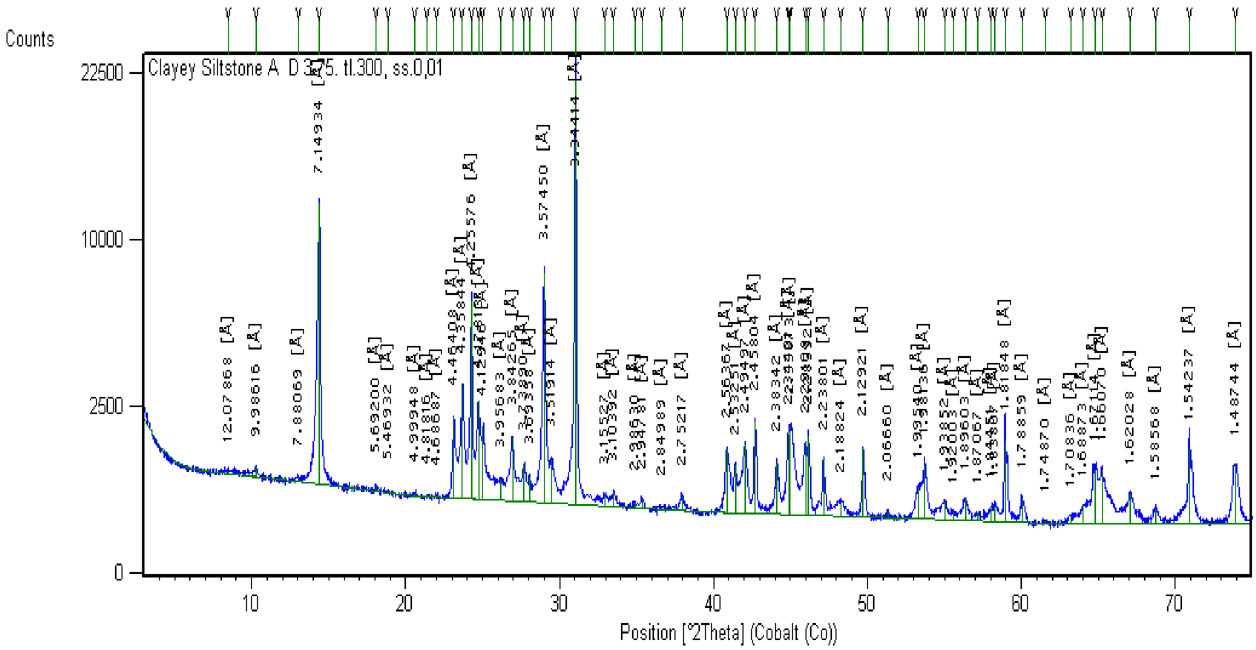

Figure 5. X-ray diffractogram showing clay and other accessory minerals of DZ12 in figure 2a (Analyzed sample is compact, grey clayey siltstone: It consists mainly of well arranged kaolinite 1Tc and quartz. A few percent of phosphate; crandallite?, probably phosphosiderite?, some illite probably together with mixed-layered structure illite/smectite ?, or mica? and traces of smectite occur).

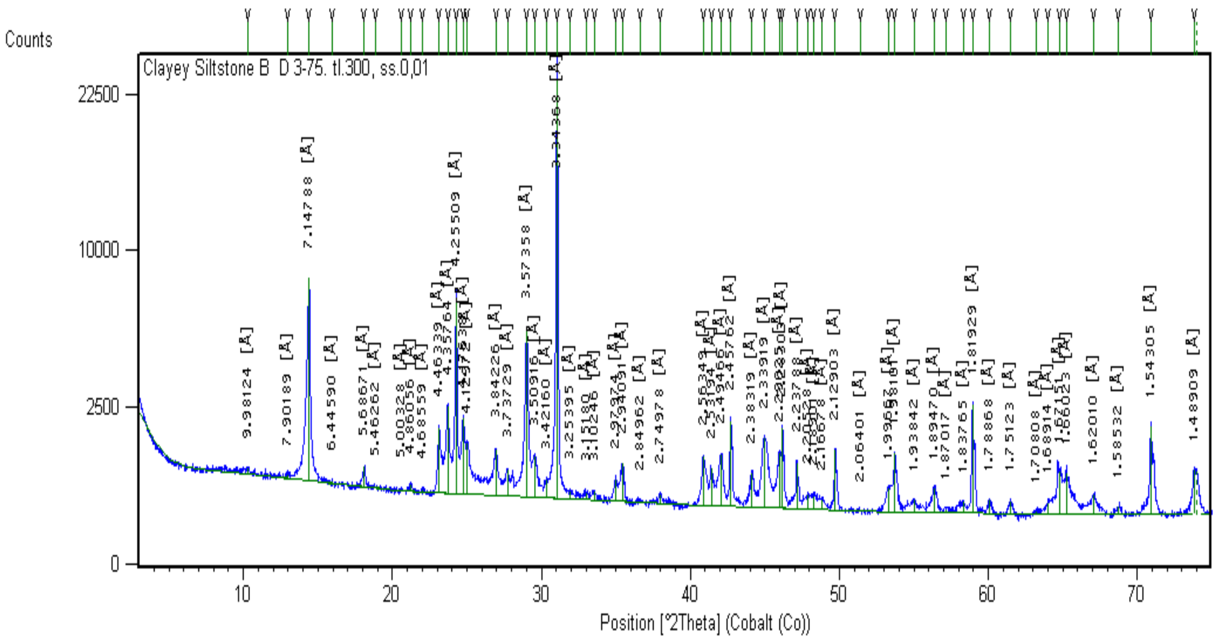

Figure 6. X-ray diffractogram showing clay and other accessory minerals of DZ14 in figure 2a (Analyzed sample is compact, whitish grey mudstone with yellowish blooms, partly porous: It consists mainly of: quartz, kaolinite 1 Tc, phosphate; crandallite?, goyazite? and probably phosphosiderite ?, admixture of illite and/or dark mica and traces of K-feldspar and smectite).