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The Cretaceous - Tertiary Clastic Rocks Weathering Indices: A case Study Of Maastrichtian?- Paleocene Rock Succession, Bornu Basin, Northestern Nigeria

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Abstract

A total number of 210 ditch cuttings samples of carbonaceous shale, sandstones and mudstones of Maastrichtian?-Paleocene sequence from Mushe , Sa, Tuma and Ziye wells from Bornu Basin were considered for this study. The intention was to understand the paleo-weathering history of the sediments. The samples collected were subjected to detail lithological and bulk geochemical analyses using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES).

The data from these analyses were evaluated using four common silicate weathering indices; Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA), Chemical Index of Weathering (CIW) and Ruxton Ratio (RR). Theseallowedfor a proper interpretation of weathering trends in reconnaissance samples from the study area.

The lithologic study showed a basin dominated by argillaceous and arenaceous sediments deposited in fluvio-marine to lagoonal settings. The results from weathering indices for Mushe, Sa, Tuma and Ziyeare CIA =79.4, 75.5, 88.7 and 82.4%;CIW=82.1, 78.2, 92.2 and 84.8%;PIA=81.7, 77.4, 91.7 and 84.5%; and RR=6.4, 11.0, 7.8 and 8.0 respectively.

The above results suggest that the weathering indices (using CIW, CIA, PIA and RR) revealed sediments subjected to short transportation, intense mechanical weathering at the source area and medium to low chemical weathering.

Keywords: Paleo-weathering, weathering indices, Bornu Basin, Maastrichtian, Paleocene

Introduction

The Bornu Basin is about one-tenth of the total areal extent of the Chad Basin which covers Nigeria, Chad, Cameroon, Niger Republic and Central African Republic, Okosun, 1995 (Fig.1). It is one of the rift related basins of geodynamic processes of plate divergence in Africa (Petters, 1981) and is a part of the Western Central African Rift System (WCARS) that was formed in response to the mechanical separation of African crustal blocks during Cretaceous and it lies within the West Africa Rift Subsystem (WAS) (Genik, 1993).

The Bornu Basin has been the focus of exploratory activities by Nigeria National Petroleum Corporation (NNPC) since early 1980s. This study will attempt to study thepalaeo-weathering activities through chemical and mechanical weathering on the sediments of this basin and its implication on the transportation history. The studies will also try to infer the possible link between the effect of palaeo-weathering and the subsequent diagenetic activities on the mineral constituents' of the sediments within the basin. For this study, four exploratory wells namely *Tuma-1, Ziye-1, Sa-1 and Mushe-1* from the basin of study were used for the work. The wells were drilled around Maiduguri by the National Petroleum Investments and Management Services (NAPIMS) - a subsidiary of NNPC at a location of about 90km North and Northwest of Maiduguri. The wells are located between latitudes 12^o15^1 and 13^o00^1N and longitudes 12^o10^1 and 12^o 20^1E. The total depths of the wells are 3925m (Mushe-1), 3627m (Tuma-1), 2458m (Sa-1) and 3360m (Ziye-1) with the spot heights of 116m. The sampling interval used for this study covered 450-750m for the four wells. This interval was picked because it covers different litho-units and the possibilities of cutting across the Cretaceous/Tertiary boundary. The Sa-1 and Ziye-1 wells are approximately 30km apart while Tuma-1 and Mushe-1 wells are approximately 50km apart respectively. (Fig 2).

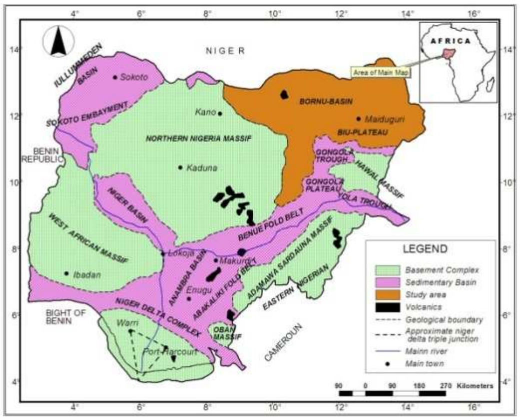

Fig. 1: Geological map showing main sedimentary basins of Nigeria and the study area (Modified after Whiteman 1982) ***(Inset map of Africa showing the position of Nigeria).***

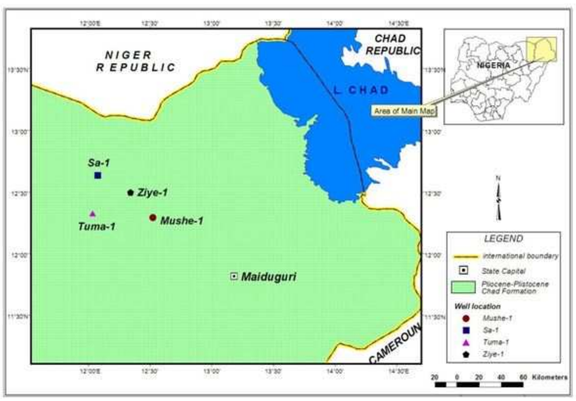

Fig. 2: Location map of the exploration wells for this study, southwestern part of Chad Basin*(inset map illustrates the position of Bornu Basin in Nigeria*)

The Geology and Stratigraphy of Bornu Basin

The Bornu Basin which is one-tenth of Chad Basin is an intra-cratonic depression in the interior of Africa – north of the equator, encompassing part of Nigeria, Cameroon, Chad Republic and Central African Republic with an area extent of about 230,000 km^2 (Matheis, 1976). Generally, subsidence is an important factor in the genesis of the Chad Basin. The Benue – Chad coaxial trough is believed to be the third and failed arm of triple junction rift system that preceded the opening of the South Atlantic during the early Cretaceous. The presence of the shallow Zambuk ridge notwithstanding, the Chad and Benue Basins are thought to be genetically related (Avbovbo et al., 1986, Olade, 1975) (Fig. 3).

The stratigraphy of the Bornu Basin has been described by Carter et al., (1963); Kogbe (1972) Petters (1981), Whiteman (1982), Avbovbo et al., (1986), Olugbemiro et al., (1997). As in other parts of Nigeria, there is no record of sedimentation between Pre-Cambrian and Late Mesozoic times. Thus, stratigraphic units represented in Bornu Basin range from Albian to Recent as exemplified in other sedimentary basins of West Africa (Petters, 1981). Deposition took place in the Bornu Basin under varying conditions and deposits represent one cycle of transgression and regression. In the Bornu Basin, Bima Formation is the oldest and the sediments age is between Albian and Cenomanian. This sequence was identified to have been deposited over localized fluvial deposit lying unconformably on the basement. These earlier sequences which are distinct and mappable are termed "Pre-Bima" and have been assigned an Albian age (Avbovbo et al., 1986; Olugbemiro, 1997). Carter et al., (1963) and Odusina et al., (1983) also reported that the Bima Formation is totally continental in the northern part of the basin, while in the south, marine shale occurs in the lower part of the sequence. These probably correspond with the Pre- Bima beds of Avbovbo et al., (1986). The sediments are continental, sparsely fossiliferous, poorly sorted, medium- to coarse-grained feldspathic sandstones which directly overlies Pre-Cambrian–Lower Palaeozoic basement rocks. The Formation is said to have been derived from the basement (granitic) terrain (Odusina et al., 1983).

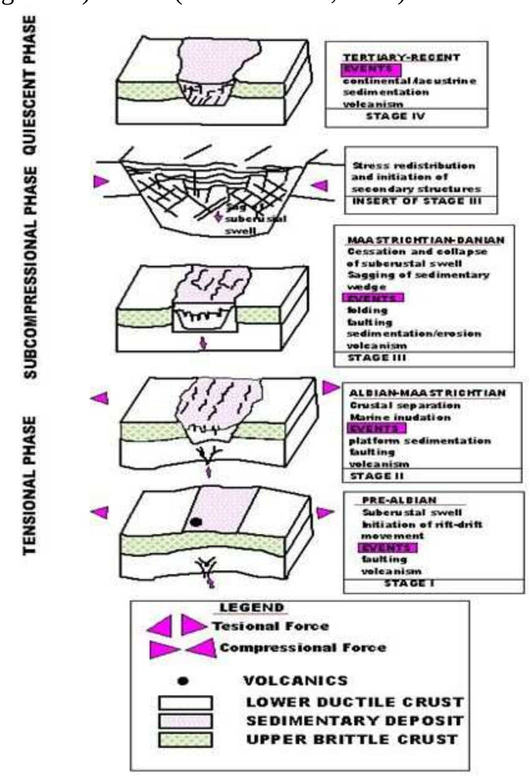

Fig 3: Diagramatic representation of structural events in the Bornu Basin (*modified after Avbovbo et al., 1986*)

The Gongilla Formation overlies the Bima Formation. Towards the end of Cenomanian, there was an extensive marine transgression which resulted in the deposition of the Gongilla Formation in a warm shallow epeiric sea. This marked the beginning of the first marine transgression into the basin (Carter et al., 1963, Avbovbo et al., 1986, Olugbemiro et al., 1997). The Formation is made up of an alternating sequence of sandstone and shale with limestone beds.
The Fika Shale came into existence during Turonian which was a period noted for the most extensive marine transgression in the Bornu Basin. At this time, Zambuk ridge was said to have submerged. The shale is bluish–black, ammonite-rich, occasionally gypsiferous and contains one or two thin impersistent limestone beds. The marine transgression (Cenomanian–Turonian) submerged a large part of African plate, reaching a maximum extent around 80Ma (Hartley and Allen, 1994) before regression led to Maastrichtian–Paleocene continental sedimentation. Fika Shale ranges from Late Turonian to Early Maastrichtian in age.
Sitting unconformably on Fika is the Late MaastrichtianGombe Sandstone which witnessed a phase of tensional deformation within the basin and this continued until the end of Cretaceous. The restructuring accompanying the deformation within the basin caused a widespread uplift, creating an elongate NE-SW graben system and the formation of a low NE-SW fold parallel to the axis of the basin (Avbovbo et at., 1986).The estuarine/deltaic sediment which characterized Gombe Formation were deposited at the southeastern shoreline of Maastrichtian Saharan sea. They are composed mainly of sandstone, siltstone, shale, clay, thin coal beds and lenticular oolitic to non-oolitic ironstones.
The Kerrikerri Formation which lies on GombeSanstone marks the beginning of the second depositional episode in the Chad Basin. It lies unconformably on the folded Cretaceous sequences, though not folded, it gently dips northwards below the Chad Formation. Structurally and lithologically, the Formation resembled Bima Sandstone although Bima is more feldspathic and consists of coarse sandstone grade. The Formation is made up of an intercalation of sandstones, gritty clays and clays. The sandstone is iron-rich and capped by vesicular and oolitic ironstone in some places and it is dated Paleocene.
Chad Formation is the youngest and the last of the sequences in the Chad Basin. It varies in lithology both vertically and laterally. Feldspathic sands dominate the base which is overlain by gravels and by a thick stratum of greenish-gray clay with a high proportion of fine -grained sandstone probably windblown sandstone. It has been divided into three members. With the exception of diatom flora**,** Chad Formation has yielded few fossils. The Formation attains its maximum thickness near Maiduguri, where it is over 800 meters thick but on the average, the thickness is 400 meters. It is believed to be Pleistocene in age.

Materials & Methods

A total of 210 samples were collected from the four wells between intervals 450-750m at 5m intervals down the hole (Table 1). This interval is believed to fall within Maastrichtian?-Paleocene age (NNPC report, 1989). The samples were systematically described and litho-log of each section was prepared. After this, the samples were subjected to ICP-AES, a well-proven analytical technique that has been in routine use for over 60 years. The methodology and technique as applied are as discussed by Greenfield et al., (1964), Jarvis and Jarvis (1992a), and Jarvis and Jarvis (1992b). Based on the above method (ICP-AES), oxides concentration values were generated for the 10 major elements Si, Al, Ti, Fe, Mg, Ca, Na, K, P and Mn (Tables 2a-d)

TABLE 1: Sampling Points/Intervals within the wells from Bornu Basin, Northeastern Nigeria

Depth (Meters)	Mushe-1 well Sample No	Sa-1 well Sample No	Tuma-1 well Sample No	Ziye-1 well Sample No
450-455	M1	S1	T1	Z1
455-460	M2	S2	T2	Z2
460-465	M3	S3	T3	Z3
465-470	M4	S4	T4	Z4
470-475	M5	S5	T5	*Missing*
475-480	M6	S6	T6	Z5
480-485	*Missing*	S7	T7	Z6
485-490	*Missing*	S8	T8	Z7
490-495	M7	S9	T9	Z8
495-500	M8	S10	*Missing*	Z9
500-505	M9	S11	T10	Z10
505-510	*Missing*	S12	*Missing*	Z11

510-515	**M10**	**S13**	**T11**	**Z12**
515-520	***Missing***	**S14**	**T12**	**Z13**
520-525	**M11**	**S15**	**T13**	**Z14**
525-530	**M12**	**S16**	**T14**	**Z15**
530-535	**M13**	**S17**	**T15**	**Z16**
535-540	***Missing***	**S18**	**T16**	**Z17**
540-545	***Missing***	**S19**	**T17**	**Z18**
545-550	**M14**	**S20**	**T18**	**Z19**
550-555	***Missing***	**S21**	**T19**	**Z20**
555-560	**M15**	**S22**	**T20**	**Z21**
560-565	**M16**	**S23**	**T21**	**Z22**
565-570	***Missing***	***Missing***	**T22**	**Z23**
570-575	**M17**	***Missing***	**T23**	**Z24**
575-580	***Missing***	**S24**	**T24**	**Z25**
580-585	***Missing***	**S25**	**T25**	**Z26**
585-590	***Missing***	**S26**	**T26**	**Z27**
590-595	***Missing***	**S27**	**T27**	***Missing***
595-600	**M18**	**S28**	**T28**	***Missing***
600-605	**M19**	Missing	**T29**	**Z28**
605-610	**M20**	**S29**	**T30**	**Z29**
610-615	**M21**	**S30**	**T31**	**Z30**
615-620	***Missing***	***Missing***	**T32**	**Z31**
620-625	**M22**	**S31**	**T33**	**Z32**
625-630	**M23**	**S32**	***Missing***	**Z33**
630-635	**M24**	**S33**	**T34**	**Z34**
635-640	**M25**	**S34**	**T35**	**Z35**
640-645	**M26**	**S35**	**T36**	**Z36**
645-650	***Missing***	**S36**	**T37**	**Z37**
650-655	**M27**	***Missing***	***Missing***	**Z38**
655-660	**M28**	**S37**	**T38**	**Z39**
660-665	Missing	**S38**	**Missing**	**Z40**
665-670	**M29**	**S39**	**T39**	**Z41**
670-675	**M30**	**S40**	**T40**	**Z42**
675-680	**M31**	**S41**	**T41**	**Z43**
680-685	**M32**	**S42**	**T42**	**Z44**
685-690	**M33**	**S43**	**T43**	**Z45**
690-695	***Missing***	**S44**	**T44**	***Missing***
695-700	**M34**	**S45**	**T45**	**Z46**
700-705	**M35**	**S46**	**T46**	**Z47**
705-710	**M36**	**S47**	**T47**	**Z48**
710-715	**M37**	**S48**	**T48**	**Z49**
715-720	**M38**	**S49**	**T49**	**Z50**
720-725	**M39**	***Missing***	**T50**	**Z51**
725-730	**M40**	**S50**	**T51**	**Z52**
730-735	**M41**	**S51**	***Missing***	***Missing***
735-740	**M42**	**S52**	**T52**	**Z53**
740-745	**M43**	**S53**	**T53**	**Z54**
745-750	**M44**	**S54**	**T54**	**Z55**

Result And Discussion

Lithostratigraphic Description of the Wells

The lithologic descriptions involved megascopic visual examination using hand lens of each collected samples from all the wells within the study area. It involved the use of hand lens and binocular microscope for recognition of colour, grain size, grain shape and sorting. The essence of this was to create a litholog through the establishment of vertical variation from the ditch cuttings and correlating such inter-well variations (Fig. 7).

Four (4) litho units were identified in the study area. These four litho units occurred in one of the four wells (Fig. 3) while another well showed three litho units (Fig.4) and the other two wells have two litho units (Figs 5 and 6). The four (4) litho units are mudrock, clayey sandstone, sandstone and shale, and they are subdivided based on the presence and the percentage of clay and grains in the rock.

Litholog Correlation

It was observed that the sedimentary sequences from the four wells correlate perfectly. The study revealed the basin having Ziye well exhibiting the thickest mudrocksequence while the sandstone unit as exposed in Sa well having the highest thickness. The shale unit occurred below the sandstone only in two of the four wells occupying the base of the wells within the interval studied (Tuma and Mushe) (Fig. 7). Furthermore, based on the location map and the position of each well within Bornu Basin, the correlation revealed a basin with possible marine transgression tending northward from the south since

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the shale was first encountered in Tuma and Mushe wells.

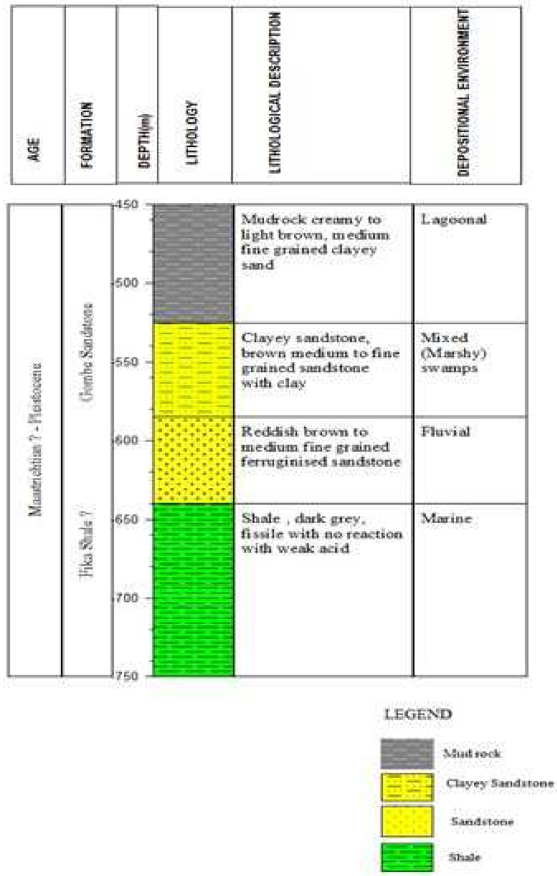

Fig. 3: Litholog of the studied portion of Mushe-1 well

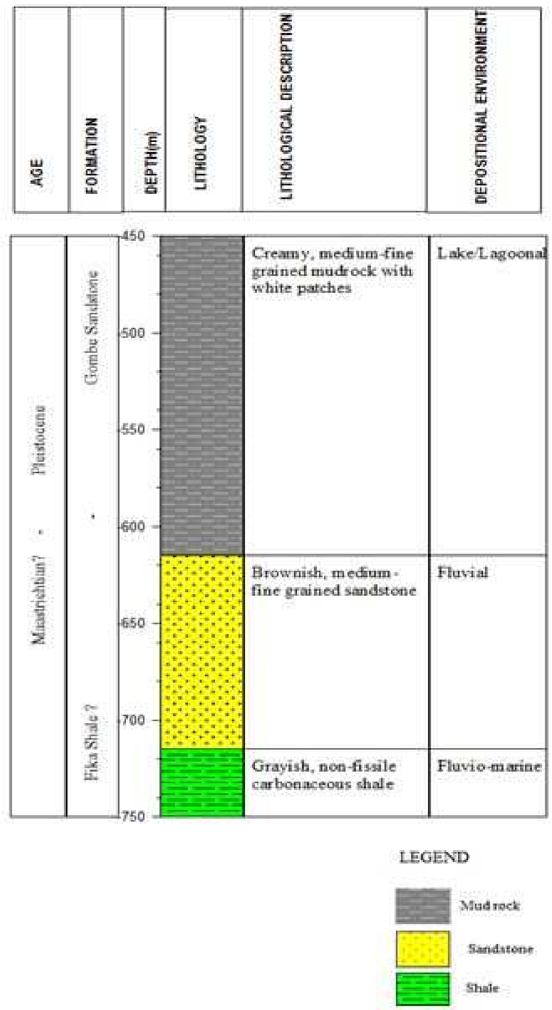

Fig.4: Litholog of the studied interval of Tuma-1 well

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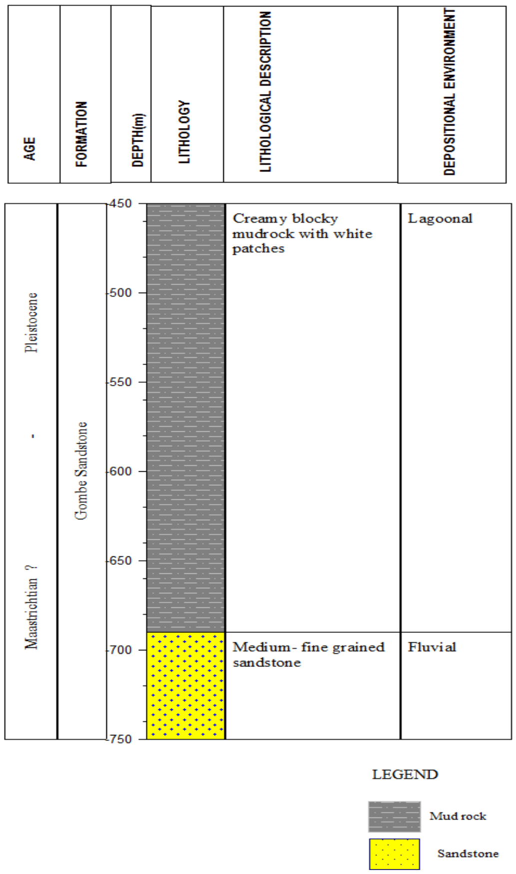

Fig. 5: Litholog of the studied interval of Sa-1 well

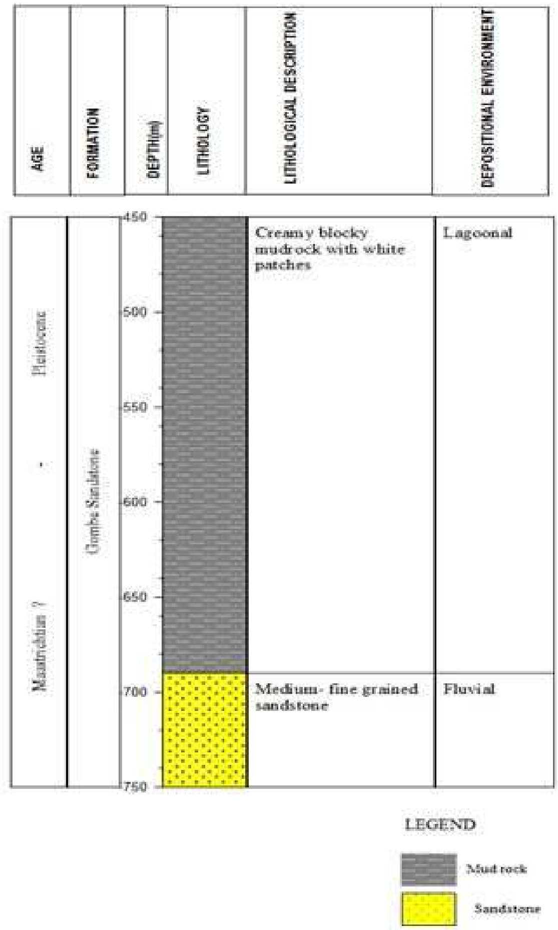

Fig. 6: Litholog of the studied interval of Ziye-1 well

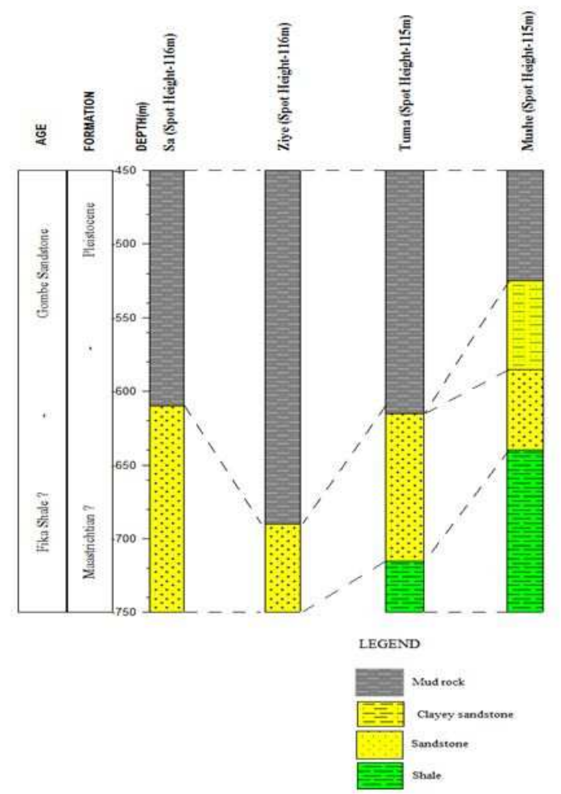

Fig. 7: Generalised correlation chart based on litholog for the studied portion of Bornu Basin, Northeastern Nigeria.

Source Area Weathering

The weathering history of an ancient sedimentary rocks can be evaluated in part by examining relationships among the alkali and alkaline earth elements (Al_2O_3, CaO, Na_2O, and K_2O) **[**Nesbitt and Young, 1982, 1984, 1989]. This is because alteration of igneous rocks during weathering results in depletion of alkali and alkaline earth elements and preferential enrichment of Al_2O_3 in sediments.

A good measure of the degree of chemical weathering can be obtained by calculating the Chemical Index of Alteration **(CIA)** (Nesbitt and Young, 1982) and Plagioclase Index of Alteration **(PIA)** (Fedo et al., 1995). High CIA and PIA values (75-100) indicate intensive weathering in the source area whereas low values (≤60) indicate low weathering in source area (Osae et al., 2006). Other indices include Ruxton Ratio used in determining the extent of weathering **(RR)** (Ruxton, 1968) and that of Chemical Index of Weathering **(CIW)** (Harnois, 1988).

The **CIA**= $100[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]$

The**PIA**=$100[\{Al_2O_3\text{-}K_2O\}/(Al_2O_3+CaO+Na_2O+K_2O)]$

The **CIW**= $100[Al_2O_3/(Al_2O_3+CaO+Na_2O)]$

The **RR**= SiO_2/Al_2O

The CIA and CIW values for the sediments of Bornu Basin are similar but highly variables down the hole. They range from ***(19.0-100.0, 31.6-97.1, 53.1-96.0 and 33.3-95.7 %)*** in Mushe, Sa, Tuma and Ziye respectively(Tables 2a-d and 3). For the PIA, the values range from ***(18.5-100.9, 31.0-98.8, 53.3-97.7*** *and* ***33.1-98.0) %*** in the same order as (Tables 2a-d and 3). This may be as a result of multiple provenances for the sediments having variable degrees of source area weathering and processes or may be due to low concentrations of the alkalis and alkaline earth elements: Al_2O_3, CaO, Na_2O, and K_2O. Nevertheless, majority of the samples have CIA and PIA values greater than 60% (Table 3) indicating moderate to high or intensive weathering in the source area. Also, the indices show that though, there was intensive weathering at the source area, the sediments did not travel far before deposition thereby explaining the angular to sub angular quartz grains seen in the thin sections (an ongoing study on the petrography of the sediment). The RR values for the sediments ranges from 2.1-23.7, 2.3-45.7, 2.7-48.1 and 3.2-49.4 for Mushe, Sa, Tuma and Ziye respectively (Tables 2a-d and 3). According to Tijani et al. (2006), RR values greater than 30 suggests weak chemical weathering while those with one digit value indicate medium level of chemical weathering. From the RR results obtained it is observed that majority of the samples have one digit value (<10) (Tables 2a-d and 3) implying medium to high levels of weathering, thus confirming the deduction made from PIA, CIW and CIA values.

Conclusion

This study has shown from the lithologic study, a basin dominated by argillaceous and arenaceous sediments deposited within fluvio-marine to lagoonal settings. Also CIA, CIW, PIA and RR values revealed sediments that have been subjected to intense mechanical weathering from the source area, medium level of chemical weathering thereby revealing moderate to intensive weathering at the source area. Though the weathering is intense, the sediment did not travel far from source as indicated by angular to sub angular quartz grains and slight chemical weathering activities in feldspar grains as seen in the petrographic study as mentioned earlier in the discussion.

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Table 3:Summary of source area weathering compared with standard

INDICES		STANDARD	MUSHE	SA	TUMA	ZIYE
CIA	*Range*	75-100	19.0-100.0	31.6-97.1	53.1-96.0	33.3-95.7
	Mean	-	79.4	75.5	88.7	82.4
	Median	-	90	90.7	94.2	91.3
PIA	*Range*	75-100	18.5-100	31.0-98.8	53.3-97.7	33.1-98.0
	Mean	-	81.73	77.4	91.7	84.5
	Median	-	93.9	93.6	96.7	93.9
CIW	*Range*	75-100	19.0-100.0	32.1-98.9	54.9-97.7	33.5-98.1
	Mean	-	82.1	78.2	92.2	84.8
	Median	-	94.2	93.8	96.8	94.0
RR	*Range*	>30	2.1-23.7	2.3-45.7	2.7-48.1	3.2-49.4
	Mean	-	6.4	11.0	7.8	8.0
	Median	-	2.8	5.0	3.9	4.7

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