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Mineralogy and Geochemistry of Mudstones of the Bama Ridge (Upper Chad Formation) Bornu Basin, North-Eastern Nigeria

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Abstract— *The mudstone of the Bama Ridge Complex that represents the upper part of the Chad Formation was evaluated for its mineralogy and major oxide concentrations in this present research. XRD analysis indicated the occurrence of quartz, anatase, plagioclase, gypsum, k-feldspars, smectite and kaolinite minerals. The dominance of smectite in the clay mineral fraction points to the presence of dry arid to semi-arid climatic conditions associated with a strong presence of hot and humid regimes. Major element geochemistry indicates that paleoweathering conditions are generally moderate for the basin but few phase of high and low weathering pulse are also common and these weathering patterns are largely governed by the paleoclimatic condition.*

Keywords— *Chad Formation, Geochemistry, Paleoeclimate.*

I. Introduction

The Bornu Basin forms the southwestern part of the Chad Basin in Nigeria and covers a landmass of about 2,335,000 sq km, bordered to the South by the Benue Trough and the Biu Plateau (Fig. 1). Apart from the prominent low sand ridge feature in the basin the Bama – Maiduguri Ridge Complex landscape the relief of the basin and is relatively flat over much of its landscape. This ridge outcrops in the South Eastern part of the of the basin and trends in a Northwest - Southeast direction over a distance of about 160km from Dar-el-Jimeil in the Republic of Cameroon, through Bama, then Maiduguri where it is best developed in thickness and ultimately begins to die out at Magumeri north – west of Maiduguri (Jones, 1959). The Bama – Maiduguri Ridge Complex stratigraphically represents the uppermost sedimentary unit of the Pliocene-Pleistocene Chad Formation and mark the ancient shoreline of the third perilacustrine transgression of the Mega Lake Chad that occurred around 7500 BP. The ridge is dominantly composed of loose sandstones but locally associated with siltstones, mudstones and claystones. The later generally outcrops and dominates the low relief eastern part of the ridge and is considered as lacustrine claystones and mudstones of the Mega Lake Chad and it is the focus of this present research (Fig. 2).

Siliciclastic rocks host sensitive records of subtle changes in provenance, environment of deposition and post-depositional alterations. Such changes reflect primary differences in the chemistry of their constituent minerals, proportions of accessory phases such as heavy minerals and clays, many of which have very distinctive major and trace-element contents. These geochemical species represent a complex function of variables that comprises of source material, weathering, physical sorting, and diagenesis (Nagarajan *et al*., 2007; Madhavaraju, 2015). Mudstones commonly account for average crustal composition of a source area more than any other sedimentary rocks and this provides important information on regional tectonic setting, provenance, weathering conditions, and sediment recycling (Cullers, 1995; McLennan et al. 2003; Spalletti *et al*., 2012).

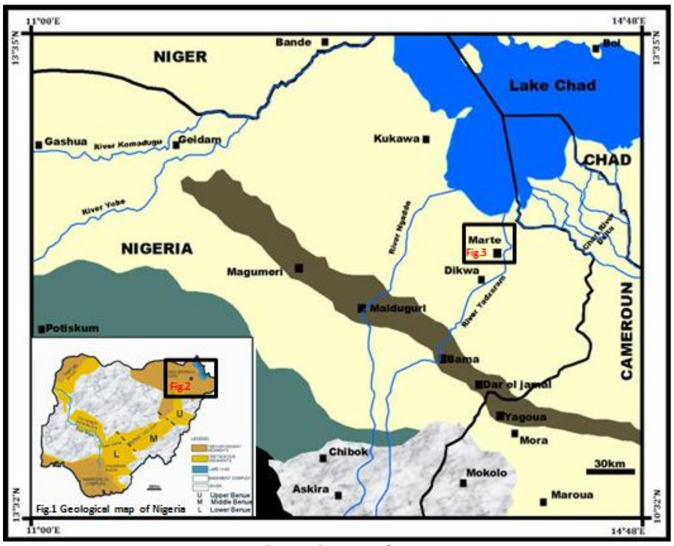

Fig. 2. Geological map of Bornu Basin.

II. Stratigraphic Setting

Sedimentation in the Bornu Basin began in the Albian with the deposition of a continental, sparsely-fossiliferous medium to the coarse grained feldspathic sandstone known as the Bima Sandstone. This formation rest directly on the Precambrian Basement Complex and it is composed mainly of sandstone and some shale intercalations (Carter *et al.*, 1963; Avbovbo *et al.*, 1986) (Fig. 3). The Bima Sandstone is conformably overlain by the Gongila Formation which is composed of calcareous shale and sandstones, deposited in a shallow marine environment (Carter *et al.,* 1963) (Fig. 3). The deposition of this formation marks the beginning of marine transgression into the Bornu Basin (Carter *et al.*, 1963). The marine transgression which started in the Cenomanian reached its peak in the Turonian during which the bluish-black, ammonites-rich open marine Fika Shale was deposited, and this deposition continued into the Santonian (Carter *et al.*, 1963). Gombe Sandstone which contain intercalation of

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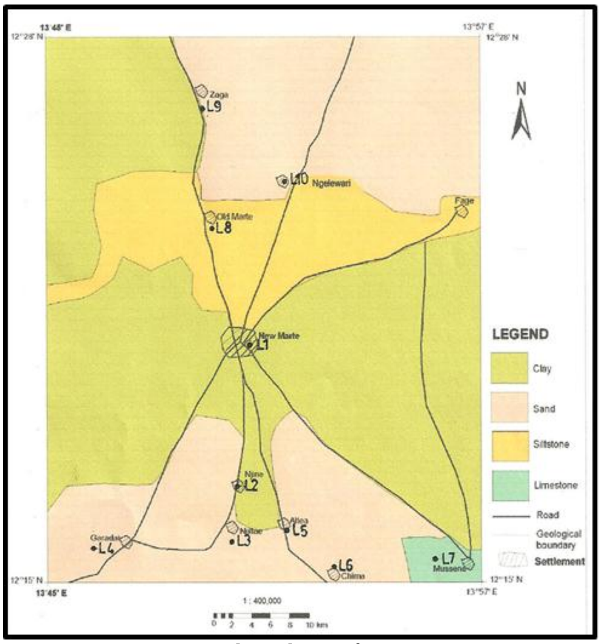

Fig. 3. Geological map of Marte area.

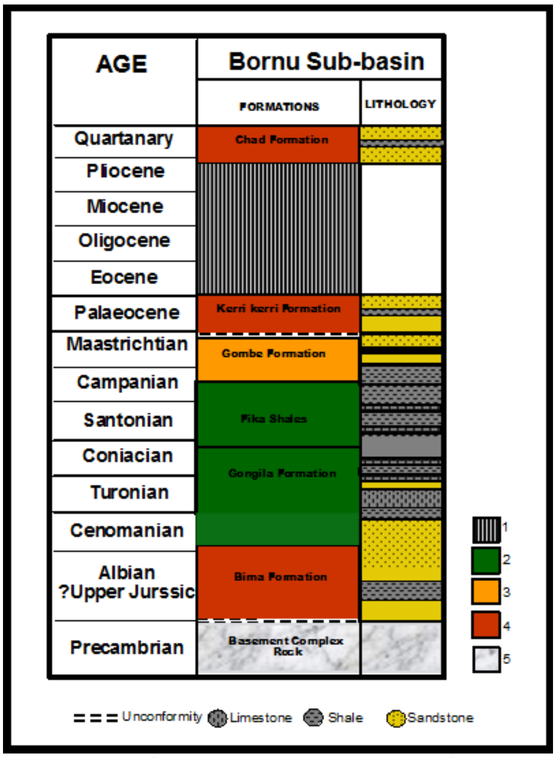

Fig. 5. Stratigraphy of Bornu Sub-basin (Chad basin) (After Carter et al.)

siltstone, shale, ironstone and sandstone was deposited in the Maastrichtian and it unconformably overlies the Fika Shale. The Paleocene Kerri-Kerri Formation unconformably overlies the Gombe Sandstone and it represents the only record of Tertiary sedimentation in the Chad Basin (Adegoke *et al.*, 1978; Dike, 1993). In the Pleistocene and presumably during the Pliocene, the continental deposit of the Chad Formation were laid down on top of the Kerri-Kerri Formation (Carter *et al.*, 1963). Toward the end of the Tertiary and until recent times, widespread volcanic activities occurred in the South and Central part of the Basin (Burke, 1976).

III. MATERIALS AND METHODS OF STUDY

Major and trace element analysed were carried out for clay samples using Inductively Couple Plasma- Optical Emission Spectrometry (ICP-OES) and X-Ray Fluorescence (XRF). With the ICP-OES (Optimal 2000DV), the elements analysed were K, Al, Ca Mg, Fe, Mn, Ti, and P. The samples were at first ashed and 0.2 g of them were digested using concentrated Nitric acid (HNO_3) and concentrated Hydrochloric acid (HCL). The samples were then introduced into the ICP-OES as liquid medium and nebulized as aerosol. The aerosol is dissolved, vaporized and atomized, then excited and ionized in order to obtain characteristic atomic radiation from where the elements and their concentration were recorded.

In the XRF analysis, SiO_2 and Al_2O_3 were determined. Five grammes (5g) of the pulverized samples were introduced into the X-Ray chamber of the minimate (PanAnalytical) XRF machine. The machine was calibrated and run having the results presented in the "result window" of the attached computer in weight percentage oxide (wt% oxide). The lost on ignition (LOI) was determined using Carbolite furnace. One gramme (1g) of the sieved samples of clay were transferred to crucibles and placed into a furnace that was set to 1000^0C for about one and a half hours. The samples were left in the furnace to cool, after which they were reweighed to determine the LOI.

Clay mineralogical analysis was carried out on 2μm clay – size fraction of 5 mudstone samples based on unoreinted X-ray powder diffractiometry (XRD) technique. X-ray identification of the clay fractionation was performed at University of Liverpool using Panalytical X pert pro MPD X-ray Diffractometer (2008) with reference patterns from international centre for diffraction data, powder Diffraction file 2 released in 2008. Equipment is set with CuKα radiation of 40kv and 40mA, Co Filters and scan range of 5 – 60^o 2Θ.

IV. RESULTS

Mineralogy

The clay mineralogy of the mudstone samples of the Chad Formation was studied at Old Marte, New Marte, Mussene, Chima, and Njine villages of Marte L.G.A. of Borno State (Fig. 5). The mineralogy generally indicated occurrence of smectite and kaolinites whereas illites and chlorite are completely absent. Smectite has least occurrence at Njine with values of 4 wt% and maximum of 32 wt% at Mussene and an average of 10.80 wt% for the study locality (Table I). Minimum value of kaolinite was recorded in New Marte and Njine at 3 wt % and maximum of 23 wt% at Mussene with an overall average of 7.80 wt %.

Other mineral occurrences were quartz ranging from 22 wt% in Mussene to 78 wt% in Njine, Plagioclase feldspar form trace amount in Njine and Mussene to 9 wt% at Chima. K-feldspar occurs with higher abundance than plagioclase feldspar ranging from 13 wt% at Old Marte and Mussene to 20 wt% at New Marte (Table I). Anatase is absent in all samples except at Mussene where it occurs in trace (1 wt%).

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Geochemistry

The geochemistry of mudstones of the Chad Formation indicated a SiO_2 range of 51.48 wt % - 62.44 wt% with an average of 55.82 wt % (Table II). Al_2O_3 varies from 12.49 wt% - 19.00 wt% and averaged 15.2 wt %. CaO ranged between 1.17 wt % and 3.39 wt % with average value of 2.01 wt %, whereas Na_2O occurs between 1.10 wt% and 8.61 wt%, with an average of 3.63 wt%. K_2O values range from 1.54 wt % to 3.66 wt % with average of 1.63 wt %. P_2O_5 varies from 0.06 wt % to 2.02 wt % with an average of 0.79 wt %. MgO and MnO occur in subordinate concentrations with the MgO varying from 0.04 wt% to 0.14 wt% averaging 0.1 wt %, while MnO ranged from 0.002 to 1.03 wt% with an average of 0.13 wt %. TiO_2 occurs in traces and ranges between 0.001 wt% to 0.02 wt% averaging 0.01 wt%. The Loss on Ignition (LOI) ranges from 6.32 % to 18.9 % with an average of 12.61%.

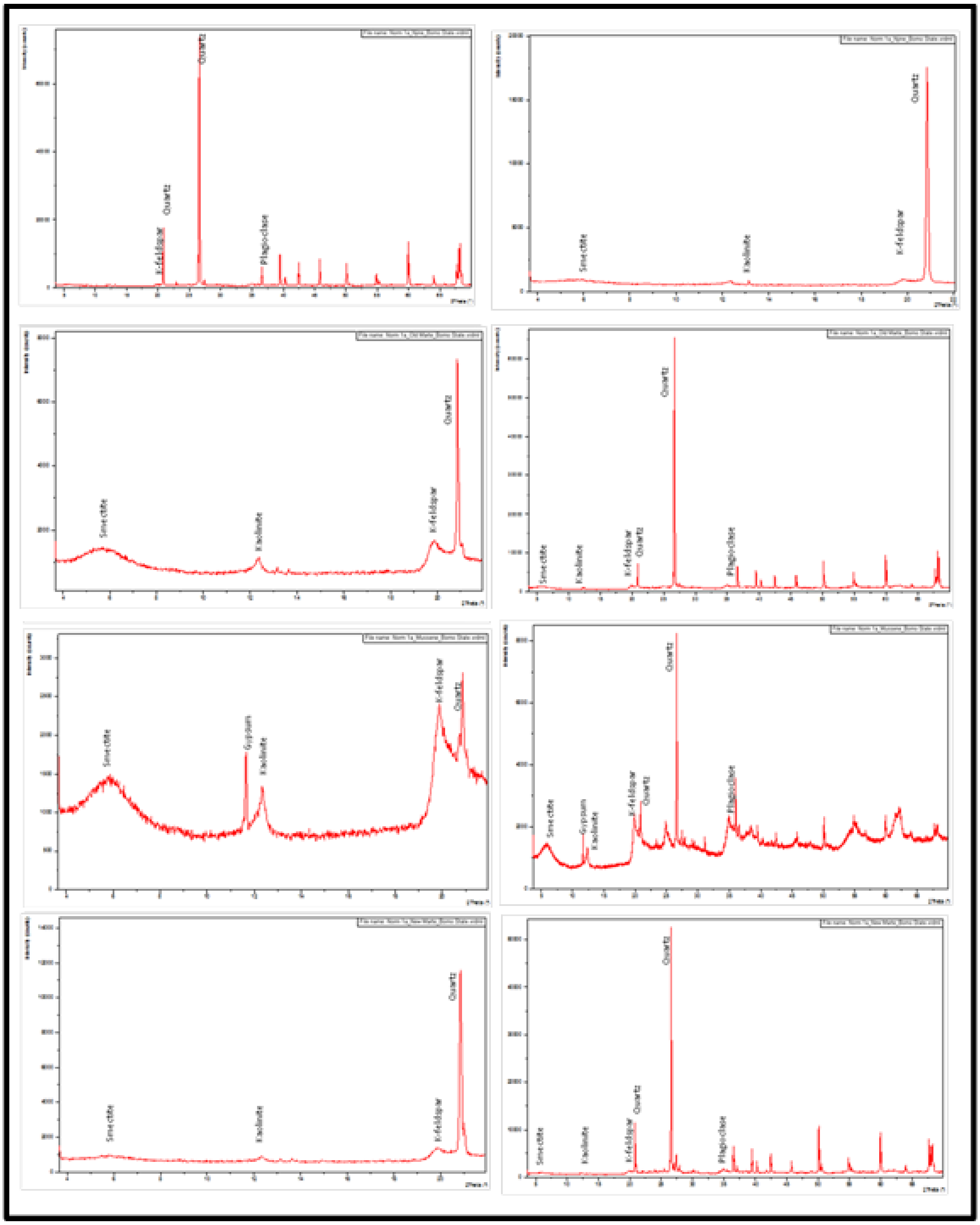

Fig. 5. XRD Diffractographs of mudstones of Marte area.

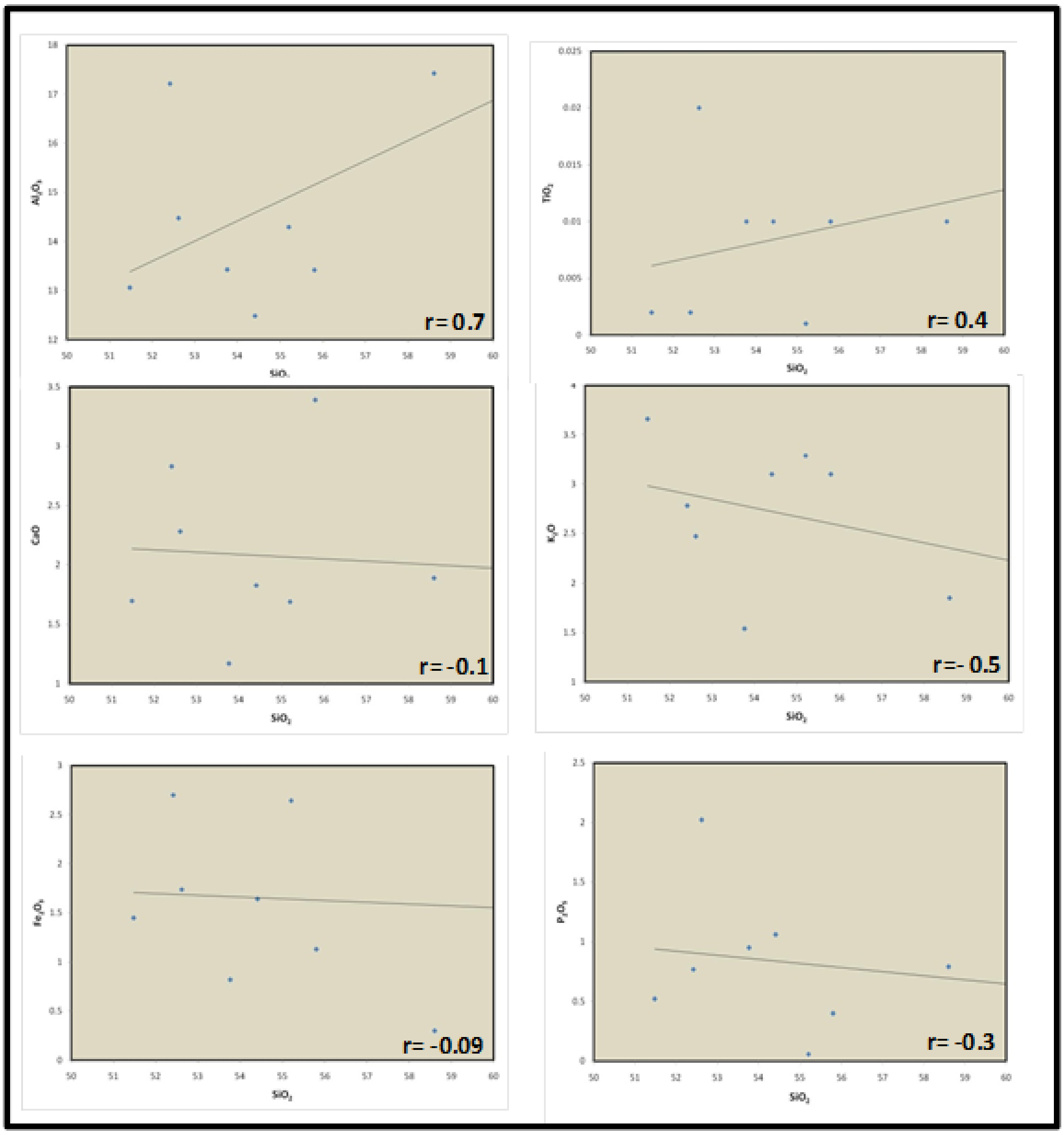

Fig. 6. Correlation plots of major oxides against SiO_2.

Regression and correlation analysis carried out for the major oxides indicated that SiO_2 correlated positively with Al_2O_3 and TiO_2 (r = 0.7 and 0.4 respectively) whereas CaO, K_2O, Fe_2O_3 and P_2O_5 correlated negatively (r = -0.1, -0.5, -0.09 and -0.3 respectively). Al_2O_3 exhibits strong negative correlation with K_2O (r = -0.4) and strong positive correlation with SiO_2 (r = 0.7). These linear trends suggest the presence of kaolinite. Al_2O_3 also shows a positive correlation with TiO_2 (r = 0.3), indicative of a probable detrital sorting trends because of their poor mobile nature (Fig. 6). Positive correlation of TiO_2 with Al_2O_3 and negative correlations of TiO_2 with several major elements (Fe_2O_3, CaO, MgO, and K_2O) points to the fact that TiO_2 occurs as a chemical constituent essentially of clays (kaolinite) rather than of mafic minerals. Its low content also suggests more evolved (felsic) source rocks (Fig. 7). The negative correlation of SiO_2 with several major elements suggests dilution of quartz (Kampunzu et al., 2005) (Fig. 6). Strong negative correlation was recorded between SiO_2 and K_2O (r = – 0.5) indicating decrease of K-bearing minerals (K-feldspar, muscovite and biotite) with increase of quartz in the mudstones. The negative correlation of CaO and P_2O_5 with SiO_2 (r = -0.1 and -0.3 respectively) suggests that the CaO was probably derived from primary carbonates but other elements may be associated with the silicates (Feng and Kerrich, 1990). Most of the samples have low P_2O_5 contents compared to post-Archean Australian average shale (PAAS; Taylor and McLennan, 1985), this depletion may account for the lesser amount of accessory phases such as apatite and monazite (Table II). Titanium is mainly concentrated in phyllosilicates (Condie *et al.*, 1992) and because of its relatively immobile nature during various sedimentary processes and therefore may strongly represent the source rocks (McLennan *et al.*, 1993). Its low value in the mudstones (Table II) below the PAAS, may suggests more evolved (felsic) material in the source rocks. K_2O/Al_2O_3 ratio are established proxy to original composition of ancient mudrocks with clay minerals constituting of values in the range of 0.0 – 0.3 and feldspars from 0.3 – 0.9 (Cox *et al.*, 1995). The K_2O/Al_2O_3 ratios for mudstones of the Chad Formation ranged between 0.13 and 0.21, suggesting that the clay minerals present in them are mostly of kaolinte and illite compositions.

V. Discussion

Paleoclimate

The variation in the assemblage of bulk- rock and clay mineralogy are records of paleoenvironmental changes induced by climatic and diagenetic conditions (Westermann et al., 2013). In view of this it is paramount to evaluate the diagenetic imprints on clay mineral assemblages before making any environmental interpretations. Authigenic clay mineral formation are commonly attributed to burial diagenesis and it has been generally demonstrated that during burial diagenesis smectite transforms to illite and chlorite associated with corresponding increase in the proportion of mixed – layers (smectite- chlorite) owing to increase in temperature and pressure (Godet et al., 2008). The samples studied are completely devoid of illite, chlorite and mixed – layers clay mineral assemblage, suggesting a significantly low diagenetic overprint indicating a relatively low impact on primary environmental signals, hence its usefulness as paleoclimatic proxy.

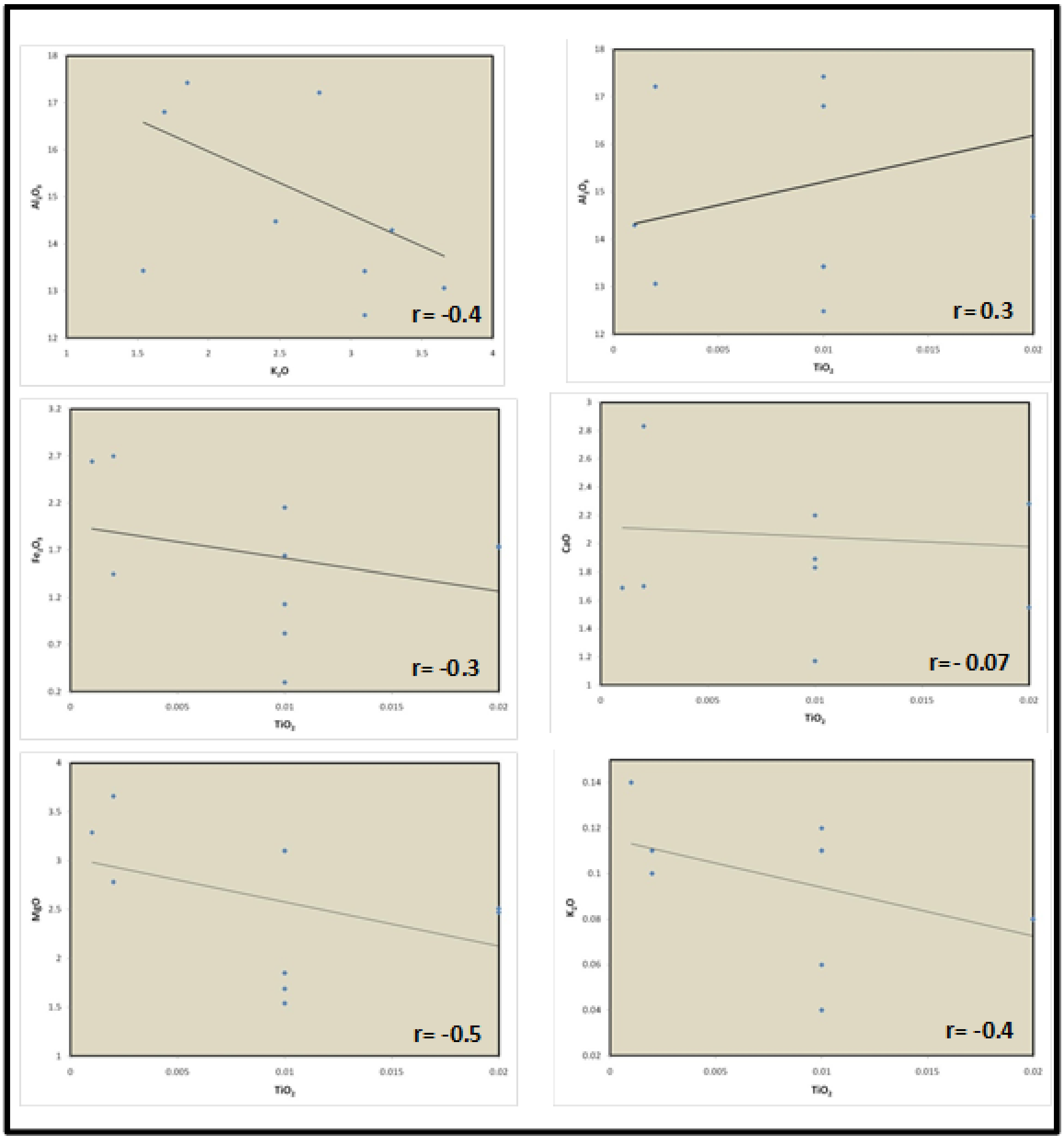

Fig. 7. Correlation plots of major oxides.

TABLE I. Mineralogy of mudstones (in wt%).

Location	New Marte (L1)	Njine (L2)	Chima (L6)	Mussene (L7)	Old Marte (L8)	Average wt (%)
Quartz	66	78	72	22	68	61.2
Anatase	ND	ND	ND	1	ND	0
Plagioclase	7		9	trace	ND	3.2
k-feldspar	20	15	15	13	13	15.2
Kaolinite	3	3	4	23	6	7.8
Smectite	5	4	Trace	32	13	10.8
Gypsum	ND	ND	ND	9	ND	1.8

Smectite is the dominant clay mineral species in the studied samples (Table I) but occurs with a relatively less difference in relative percentage to its subordinate kaolinite mineralization (av. 10.8% and av. 7.8% respectively). Smectite forms under warm and humid conditions in the arid to semi – arid climatic setting (Chamley, 1989; Raucsik and Varga, 2008), whereas kaolinite develops in a humid – subtropical climatic condition, characterized by relatively high rainfall and intense chemical weathering (Ruffell et al., 2005). Therefore, this may suggest that the evolution of the mudstone of the upper part of the Chad Formation is characterized by two contrasting seasons of wet – humid leading to the development of smectite and hot- wet – humid generating kaolinite.

Paleoweathering Conditions

The relationship between alkali and alkali earth metals are generally proxy to weathering process in sedimentary rocks (Nesbitt and Young, 1982). Commonly labile elements (Na, Ca, Sr) are usually leached during weathering leaving behind insoluble and immobile elements (Al, Ba, Rb) along the weathering profile (Nesbitt et al., 1987). The selective degree of mobility and segregation of these chemical species are typically reflected in sedimentary units, and this provides a useful tool for evaluating source area weathering conditions (Wronkiewiez and Condie, 1987).

Nesbitt and Young (1982) introduced a measure of determining the degree of source area weathering called the Chemical Index of Alteration (CIA). The chemical index is determine using molecular proportion of major oxides and calculated on the basis of this formula CIA = $(Al_2O_3/Al_2O_3+CaO^*+Na_2O+K_2O)*100$, where CaO* is the amount of CaO associated with the silicate fraction of the rock. CIA value gives the relative proportions of secondary aluminous clay minerals to primary silicate minerals like feldspars (Nesbitt and Young, 1982). The higher CIA values (76 to 100) in the sedimentary rocks suggest the intense chemical weathering in the source region (Fadipe *et al*., 2011; Srivastava *et al*., 2013; Újvarí *et al*., 2013), whereas low values (50 or less) indicate the near absence of chemical weathering and also reflect cool and arid conditions (Fedo *et al*., 1995). The generality of the values in this study are above 50 and most are below 76 (Table I). Therefore, the observed CIA values in the mudstone indicate a dominantly moderate chemical weathering intensity in the source rocks and few episodes of high intense and very low weathering conditions (i.e. Fedo *et al*., 1995). Another index to measure the chemical weathering of sediments and sedimentary rocks is Plagioclase Index of Alteration (PIA: Fedo *et al*., 1995), which can be calculated as follows: PIA = $[(Al_2O_3 - K_2O)/(Al_2O_3+Na_2O+CaO^*-K_2O)] \times 100$ (molecular proportions). The PIA values ranged from 46 – 84 and this is consistent with CIA values which further support that these mudstones had undergone dominant moderate intensity of chemical weathering. The Chemical Index of Weathering, CIW = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O)] \times 100$, gave values of 53 – 86 for the mudstones which also indicated a moderate degree of weathering, further agreeing with earlier inferences.

TABLE II. showing major oxide concentration of mudstones (in wt%).

Major Oxides	New Marte	Chima	Njiltae	Njine	Allea	Mussene	Ngelewari	Garadai	Old Marte	Zaga	PAAS
SiO_2	52.62	53.77	51.48	54.42	62.44	52.42	61.40	58.61	55.20	55.80	62.40
TiO_2	0.02	0.01	0.00	0.01	0.02	0.00	0.01	0.01	0.00	0.01	0.99
Al_2O_3	14.48	13.43	13.06	12.49	19.00	17.21	16.80	17.42	14.30	13.42	18.78
Fe_2O_3	1.74	0.82	1.45	1.64	1.73	2.70	2.15	0.30	2.64	1.13	7.18
MgO	0.08	0.06	0.11	0.11	0.08	0.10	0.11	0.04	0.14	0.12	2.19
CaO	2.28	1.17	1.70	1.83	1.55	2.83	2.20	1.89	1.69	3.39	1.29
Na_2O	5.21	4.59	6.52	2.75	1.58	1.50	2.47	1.10	2.00	8.61	1.19
K_2O	2.47	1.54	3.66	3.10	2.51	2.78	1.69	1.85	3.29	3.10	3.68
P_2O_5	2.02	0.95	0.52	1.06	0.70	0.77	0.63	0.79	0.06	0.40	0.16
MnO	0.03	0.01	0.01	0.03	0.00	0.03	0.04	0.01	0.06	1.03	0.11
LOI	18.95	16.81	16.43	11.00	6.32	12.42	7.30	14.20	13.30	9.40	
K_2O/Al_2O_3	0.17	0.11	0.28	0.25	0.13	0.16	0.10	0.11	0.23	0.23	

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VI. Conclusion

The mudstones of the Bama Ridge Complex (Upper Chad Formation) are composed solely of Smectite and kaolinite clay mineral species. Dominant occurrence of smectite in these mudstones provides an account of the prevalence arid to semi – arid climatic settings defined by hot and dry conditions. This setting is also interfaced with hot and humid condition as indicated by the relative kaolinite mineralization in the mudstones. These paleoclimatic records reflect the relicts of the current climatic regimes that commonly characterize the basin today with the northeast trade wind accompanied with dry arid conditions and southwest trade wind with wet and humid conditions. The paleoweathering conditions shows much of moderate chemical weathering intensity of the source rocks and this may be as a consequence of the interacting episodes of dry arid and wet humid climatic regimes.

References

[1] Adegoke, O.S., Jan du Chew, R.E., Agumanu, A.E. and Ajayi, P.O. 1978. Palynology and age of the Kerri-Kerri Formation, Nigeria, Revista Espanola Micropalacotologia 10, 2-283.

[2] Avbovbo, A.A., Ayoola, E.O and Osahon, G.A.,1986. Depositional and structural styles in Chad Basin of northeastern Nigeria. American Association Petroleum Geologists Bulletin, 70: 1787-1798.

[3] Burke. K. C., 1976. The Chad Basin: An active intra-continental basin. Techtonophysics, 36, 197-206.

[4] Carter, J.D., Barber, W., Tait, E.A and Jones, G.P., 1963. The geology of parts of Adamawa, Bauchi and Borno provinces in north-eastern Nigeria. Geological Survey Nigeria Bulletin,30:1-99.

[5] Chamley, H., 1989. Clay Sedimentology. Springer Verlag, Berlin. New York, 67p,

[6] Condie, K.C., Boryta, M.D., Liu, J. and 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.

[7] Cox, R., Lowe, D.R. and Cullers, R.L., 1995. The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States: Geochimica et Cosmochimica Acta, 59, 2919-2940.

[8] Cullers, R.L., 1995. The controls on the major and trace element evolution of shales, siltstones and sandstones of Ordovician to Tertiary age in the Wet Mountain region, Colorado, USA: Chemical Geology, 123, 107-131.

[9] Dike, E.F.C., 1993. The Statigraphy and structure of the Kerri-Kerri Basin Northeastern Nigeria. Jour. Min. Geol.29, 2, 77-93Du,Preez,1949;

[10] Fadipe, O.A., Carey, P.F., Akinlua, A. and Adekola, S.A., 2011. Provenance, diagenesis and reservoir quality of the Lower Cretaceous sandstone of the Orange Basin, South Africa: South African Journal of Geology, 114, 433-448.

[11] Fedo, C.M., Nesbitt, H.W. and Young, G.M., 1995. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosoils, with implications for paleoweathering conditions and provenance: Geology, 23, 921-924.

[12] Feng, R. and Kerrich, R.,1990. Geochemistry of Fine-Grained Clastic Sediments in the Archean Abitibi Greenstone Belt, Canada: Implications for Provenance and Tectonic Setting. Geochimica et Cosmochimica Acta, 54, 1061-1081.

[13] Godet, A., Bodin, S., Adatte, T. and Föllmi, K., 2008. Platform-induced clay-mineral fractionation along northern Tethyan basin-platform transect: implications for the interpretation of Early Cretaceous climate change (Late Hauterivian-Early Aptian): Cretaceous Research, 29, 830-847. Jones,1959

[14] Kampunzu, A.B., Cailteux, J.L.H., Moine, B. and Loris, H.N., 2005. Geochemical characterisation, provenance, source and depositional environment of 'Roches Argilo-Talqueuses' (RAT) and Mines Subgroups sedimentary rocks in the Neoproterozoic Katangan Belt (Congo): Lithostratigraphic implications. J Afr Earth Sci 42:119–133

[15] Madhavaraju, J., 2015, Geochemistry of Campanian-Maastrichtian sedimentary rocks in the Cauvery Basin, South India: Constrains on paleoweathering, provenance and Cretaceous environments, *in* Ramkumar, M. (ed.), Chemostratigraphy: Concepts, Techniques and Applications: Elsevier Special Volume, 185-214.

[16] Mclennan, S.M., Bock, B., Hemming, S.R., Hurowitz, J.A., Lev, S.M., and Mcdaniel, D.K., 2003. The roles of provenance and sedimentary processes in the geochemistry of sedimentary rocks, in Lentz, D.R., ed., Geochemistry of Sedimentsand Sedimentary Rocks: Evolutionary Considerations to Mineral Deposit-Forming Environments: Geological Association of Canada, GeoText 4, 7–38.

[17] McLennan, S.M., 1993. Weathering and global denudation: The Journal of Geology, 101, 295-303.

[18] Nagarajan, R., Madhavaraju, J., Nagendra, R., Armstrong-Altrin, J. S. and 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, 150-160.

[19] Nesbitt, H.W. and Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites: Nature, 299, 715-717.

[20] Nesbitt, H. W. and G. M. Young (1989). "Formation and Diagenesis of Weathering Profiles. The Journal of Geology **97**(2): 129-147.

[21] Raucsik, B. and Varga A. 2008. Climato-environmental controls on clay mineralogy of the Hettangian–Bajocian successions of the Mecsek Mountains, Hungary: An evidence for extreme continental weathering during the early Toarcian oceanic anoxic event.

[22] Palaeogeography, Palaeoclimatology and Palaeoecology, 265, 1 – 13.

[23] Ruffell, A., McKinley, J.M. and Worden, R.H., 2002. Comparison of clay mineral stratigraphy to other proxy palaeoclimate indicators in the Mesozoic of NW Europe. Phil. Trans. R. Soc. Lond. A 360, 675–693.

[24] Spalletti, L.A., Limarino, C.O. and Pinol, F.C., 2012. Petrology and geochemistry of Carboniferous siliciclastics from the Argentine Frontal Cordillera: A test of methods for interpreting provenance and tectonic Setting: Journal of South America Earth Science, 36, 32-54.

[25] Srivastava, A.K., Randive, K.R. and Khare, N., 2013. Mineralogical and geochemical studies of glacial sediments from Schirmacher Oasis, East Antarctica: Quaternary International, 292, 205-216.

[26] Taylor, S.R. and McLennan, S.M., 1985. The Continental Crust: its Composition and Evolution: Oxford, Blackwell, 349 pp.

[27] Újvarí, G., Varga, A., Raucsik, B. and Kovács, J., 2013. The Paks loess-paleosol sequence: a record of chemical weathering and provenance for the last 800 ka in the mid-Carpathian Basin: Quaternary International, http:// dx.doi.org/10.1016/j.quaint. 2012. 04.004.

[28] Westermann, S., Duchamp-Alphonse, S., Fiet, N., Fleitmann, D., Matera, V., Adatte, T., Follmi, K.B., 2013, Paleoenvironmental changes during the Valanginian: New insights from variations in phosphorous contents and bulk-and clay mineralogies in th western Tethys: Paleogeography Paleoclimatology Paleoecology, 392, 196-208.

[29] Wronkiewicz, D.J., Condie, K.C., 1987, Geochemistry of Archean shales from the Witwatersrand Supergroup, South Africa: source-area weathering and provenance: Geochimica et Cosmochimica Acta, 51, 2401-2416.

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