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Geochemistry and mineralogy of the Campanian Sandstone of Lokoja-Basange Formation, Middle Niger Basin (Lokoja sub-basin), Nigeria: Implications for provenance, weathering, tectonic setting and paleo-redox condition

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Abstract

Twenty six road-cut sandstone samples from two lithological sections of Lokoja-Basange Formation in Middle Niger Basin (Lokoja sub-basin) situated by the side of Auchi-Igarra road (07 ° 07.201'N, 006 ° 13.011'E) were investigated using integrated mineralogical, geochemical and pore water chemistry studies. The medium to coarse grained sandstone bodies are poorly sorted suggestive of deposition in a low energy setting, probably in a shelf or floodplain. The observed variations in the sandstone colourations are attributed to the nature of the cementing materials. Based on the mineralogical composition, two specific geochemical intervals were established; the first interval revealed quartz and kaolinite as major crystalline minerals with traces of hematite. The second geochemical interval showed quartz and kaolinite as the major crystalline minerals with minor quantities of grossite and halloysite. The geochemical datasets obtained revealed mature, lithic arenites including sub-greywacke and protoquartzites. The inverse correlation between redox potential (Eh) and electrical conductivity (EC), total dissolved solids (TDS) and Mg (at 0.05 significant levels) suggest well oxygenated environment of deposition. The high chemical index of alteration (CIA), plagioclase index of alteration (PIA), and chemical index of weathering (CIW) indices revealed high detrital input dominated by intense chemical weathering. This process eventually led to the formation of clay minerals by hydration and leaching of all major cations, such as Ca^{+2}, K^{+}, and Na^{+}, present in feldspar minerals. The average mineralogical index of alteration (MIA) values are indicative of intense to extreme weathering of mineralogical component of the detrital materials from the source areas. The studied sandstones samples are plotted in the field of the active and passive continental margin settings. The mean ratio of Ti/Zr also corroborates active and passive continental margin settings. The higher ratios of La/Y and La/Th and corresponding lower ratios of La/Co and Th/Co indicates felsic source rock. Moreover, the lower ratios of Ba/Sr, Cr/Zr, Ti/Zr and higher ratio of Zr/Y probably suggest felsic source rock. Based on the previously established thresholds, the low Cu/Zn ratios in the studied sandstone samples suggest deposition under oxidizing conditions.

Keywords: Lokoja-Basange Formation, Middle Niger Basin, Mineralogy, Geochemistry, Pore water chemistry, provenance, tectonic setting, weathering, Redox proxy.

1. Introduction

This paper demonstrates the geochemical composition of Campanian sandstones from Lokoja-Basange Formation of the Middle Niger Basin (Lokoja Sub-basin) (Fig. 1) based on the 26 outcrop samples collected from two profiles. The Campanian sandstone outcrop samples used in this study are encountered at the height ranges between 0.0 - 6.5m and 0.0 - 5.5m in profiles A and B respectively. The detrital sedimentary sequence comprise of subequal proportions of alternating sandstones and clay at the lower part of profile A. The northern and southern Middle Niger (Bida) basins comprises of about 3km thick Campanian to Maastrichtian continental to shallow marine sediments. The southern Middle Niger (Bida) Basin comprises of the basal Campanian Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, claystone and sandstone) and the youngest Agbaja Formation (Ironstone). Their lateral stratigraphic equivalents in the northern Bida Basin consist of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation (Ironstone). The compositions of clastic rocks are affected by several factors, such as hydraulic sizing, tectonic environment, diagenesis, weathering and transportation processes (Taylor

&Mclennan, 1985; Wronkiewicz & Condie, 1987; Wronkiewicz & Condie, 1989). The major assumption proposed for sandstone provenance studies is that each tectonic setting consist its own rock type (Dickson and Suczek, 1979; Dickson, 1985). Although some geochemical ratios can be altered during weathering during oxidation (Taylor and McLennan, 1985) or diagenesis (Nesbit and Young, 1989; Milodowski and Zalasiewicz, 1991), as long as the bulk chemical composition is not totally altered, the geochemical composition of sediments is an important tool in the study of provenance (Bakkiaraj et al., 2010; Taylor and McLennan, 1985; Bhatia, 1983). The integration of petrography and geochemistry data of sedimentary rocks can reveal the nature of source rocks, the tectonic setting of sedimentary basins, and paleoclimatic conditions (Dickinson and Suczek, 1979; Valloni and Mezzardi, 1984; Bhatia and Crook, 1986; McLennan et al., 1993; Armstrong-Altrinet al., 2004; Al-Juboury, 2007; Jafarzadeh and Hosseini-Barzi, 2008; Ikhane et al., 2011; Akintola et al., 2012).

The major element discrimination diagrams of Bhatia (1983) have been usually used to classify the tectonic settings of sedimentary basins and was applied in recent study (e.g., Armstrong-Altrin et al., 2004), even though caution is required in their arbitrary use (Armstrong-Altrin and Verma, 2005). The most essential clues for the tectonic setting of basins come from the relative depletion of the oxides like CaO and Na_2O (the most mobile elements), among others. The oxides are understood to show enrichment or depletion of quartz, K-feldspars, micas and plagioclase. The ratio of the most immobile elements to the mobile ones increases towards the passive margin to the relative tectonic stability (Armstrong-Altrin et al., 2004) and hence indicating prolonged weathering.

Trace elements are almost certainly transferred quantitatively into clastic sediments during weathering and transportation, reflecting the signature of the parent materials, and hence are expected to be more useful in discerning tectonic environments and source-rock compositions than the major elements (Bhatia and Crook, 1986; McLennan, 1989; Condie, 1993). Conversely, rare earth elements (e.g., La, Ce, Nd, Gd, Yb), Y, Th, Zr, Hf, Nb, and Sc) are most suited for the discrimination of provenance and tectonic setting because of their relatively low mobility during sedimentary processes and their short residence times in seawater (Taylor and McLennan, 1985; Bhatia & Crook, 1986; Wronkiewicz & Condie, 1987, 1989 and 1990). Consequently, elemental ratios such as La/Sc, La/Co, Th/Sc and Zr/Cr have been found to be good discriminators between mafic and felsic source rocks (Tijani et al., 2010). Trace elements such as La, Th and Zr are said to be more concentrated in felsic igneous rocks while Co, Sc and Cr have higher concentrations in mafic rocks (Ronov et al., 1974; Wronkiewicz and Condie, 1987, 1990).

Previous studies focused on the sedimentology and depositional environments of the sediments in the northern Middle Niger (Bida) Basin suggested alluvial to braided stream depositional processes (Adeleye, 1974; Braide, 1992b; Olaniyan and Olabaniyi, 1996; Ojo and Akande, 2011). Recent studies showed considerable evidence of alluvial to coastal marine processes in the sedimentation of the Lokoja and Patti Formations in southern Bida Basin (Ojo and Akande, 2003 and 2009). A detail palynological study by Ojo and Akande (2008) and Ojo (2010) reported occurrence of biostratigraphic significant dinoflagellates of Mastrichtian age and accordingly re-affirm the Maastrichtian age (Jan du Chene et al., 1978) for the Patti shales. The ironstones of the Agbaja Formation have also attracted the noteworthy attention of researchers. Ladipo et al. (1994) suggested that the oolitic ironstones of Agbaja Formation contain high primary kaolinitic clays that were subsequently reworked into ooids by shallow marine waves and tides. Abimbola (1997) and Abimbola et al. (1999) reported kaolinite replacement by haematite and goethite. This present study is typically focused towards evaluating major and trace element geochemistry of the Campanian sandstones in the Lokoja-Basange Formation, Middle Niger Basin (Lokoja sub-basin) predicting the distribution pattern of the elements, reveals the main minerals present and as a result inferring their provenance, tectonic settings, weathering signatures and paleo-redox condition.

2. Geological setting of Middle Niger basin

The Middle Niger (Bida) Basin is a linear intracratonic sedimentary basin situated in central Nigeria. It trends NW – SE and roughly perpendicular to the Benue Trough. It is separated from the basal continental bed of the Sokoto Basin by a narrow outcrop of the crystalline basement rocks in the west and it is adjacent to the Anambra Basin in the east (Fig.1). The basin occupies a gently down warped trough (Osokpor and Okiti, 2013). The epeirogenesis responsible for the basin genesis appears closely connected with the Santonian tectonic crustal movements which mainly affected the Benue Basin and SE Nigeria. The underlain basement complex perhaps has a high relief (Jones, 1955) and the thick sedimentary successions is approximately 2000 metres as shown by gravity survey (Ojo and Ajakaiye, 1976], comprised of unfolded post-tectonic molasse facies and thin marine strata. Borehole logs, Landsat images interpretation, and Geophysical data across the basin suggest that it is bounded by a NW-SE trending system of linear faults (Kogbe et al., 1983). Gravity survey studies also corroborate central positive anomalies flanked by negative anomalies (Ojo, 1984; Ojo and Ajakaiye, 1989). This trend agreed with rift structures as observed in the adjacent Benue Trough/Basin. A detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic facies to lacustrine facies (Braide, 1992). Consequently, a simple sag and rift origin earlier suggested may not account for the basin's evolution (Osokpor and Okiti, 2013). Braide (1992a) paleogeographic reconstruction suggests lacustrine environments were widespread and elongate. Lacustrine environments occurred at the basin's axis and close to the margins. This suggests that the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5 km thick sedimentary fill (Osokpor and Okiti, 2013).

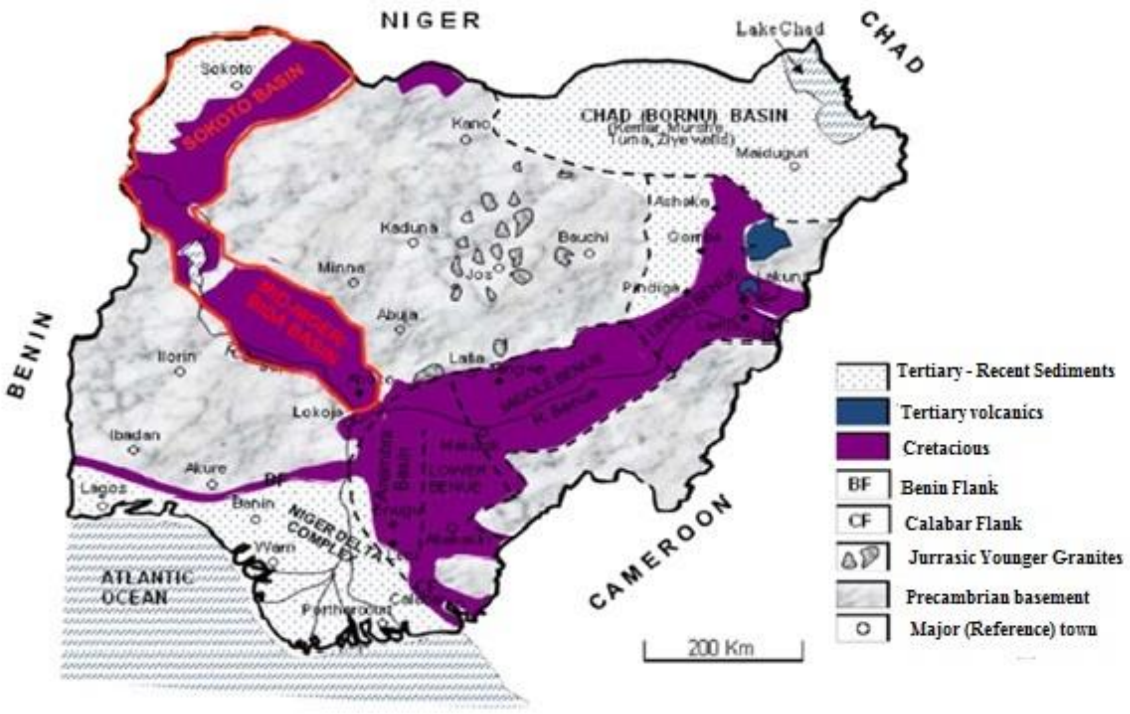


Figure 1. Geological map of Nigeria showing locations of Middle Niger Basin (After Obaje *et al.*, 2004).

The sedimentary sequences are Late Cretaceous (Campanian – Maastrichtian) in age and were named the Nupe Sandstone by Russ (1930). Adeleye (1972) subdivided Nupe sandstone (Group) into four formations: Bida Sandstone (oldest), Sakpe Ironstone, Enagi Siltstone and Batati Ironstone (youngest). A lateral facies variation occurs in the basin. Around Lokoja, the sequence is usually referred to as the Lokoja Sandstone. Nonetheless, the Sandstone is only partly equivalent to the Nupe Sandstone (Dessauvagie, 1975) and is overlain by Patti Formation (Jones, 1955). The Bida area and Lokoja area are considered separately as the stratigraphy as different. The Lokoja, Patti and Agbaja Formations occur as the three formational units in the southern Middle Niger basin (Osokpor and Okiti, 2013). The Lokoja Formation consists of pebbly clayey grit and sandstone, coarse-grained cross bedded sandstone, and few thin oolitic iron stones. A basal conglomerate of well-rounded quartz pebbles in a matrix of white clay is rarely exposed. Its thickness depends on the relief of the underlying Basement Complex floor and varies between 100 and 300 metres (Dessauvagie, 1975).

The Patti Formation is a sequence of fine to medium-grained, grey and white sandstones, carbonaceous siltstone, clay stone, shale and oolitic ironstone. Thin coal seams may be present and white gritty clays are common. The maximum exposed thickness is 70 m (Jones, 1955), while the oolitic ironstones range from 7-16 m thick. The strata yielded a few non-diagnostic plant remains (Dessauvagie, 1975). A Maastrichtian (and possibly Senonian) age was thus assigned to it based mainly on correlation with other formations e.g. the Nupe Sandstone and Enugu Shale of Campano-Maastrichtian age (Jan Du Chene et al., 1979) have recorded a palynomorph assemblage and a foraminifera fauna respectively from the Lokoja area. The micro fauna is considered to be a marsh assemblage. The palynomorphs are made up mainly of pollen and spores, the assemblage of which is indicative of a Maastrichtian age (Jan Du Chene et al., 1979). Dessauvagie (1975) shows that Patti formation yielded fossil plants (from the carbonaceous beds) dates the formation as Campanian to Maastrichtian.

3. Materials and method

The sampling technique, sample pre-treatment and analytical techniques are reported in our previous study (Akinyemi et al., 2013). The details are also reported as follows;

3.1 Sampling technique and sample pre-treatment

The Campanian sandstone outcrop located at Auchi-Igarra road, Edo state, Nigeria (07 º07.201'N, 006 º13.011'E; 230m above sea level) (Fig. 2) was sampled. 500 grams of sandstone samples were collected at an interval of 0.5m from two profiles in the road-cut sandstone exposure. All the 26 sandstone samples were immediately stored in zip lock polyethylene bag and preserved at a room temperature. The samples were dried at 60 ℃ and then ground to fine powder and homogenized in an agate ball mill. The pulverized sandstone samples were analysed using XRD, XRF and LA-ICPMS techniques.

3.2. XRF and LA-ICPMS analyses

The elemental data were acquired using X- ray fluorescence (XRF) and Laser Ablation-inductively coupled plasma spectrometry (LA-ICPMS) analyses. The detailed analytical procedures are as follows;

Pulverised sandstone samples were analysed for major elements using Axios instrument (PANalytical) with a 2.4 kWatt Rh X-ray Tube. Further, the same set of samples were analysed for trace elements using LA-ICPMS instrumental analysis. LA-ICP-MS is a powerful and sensitive analytical technique for multi-elemental analysis. The laser was used to vaporize the surface of the solid sample and it was the vapour, and any particles, which were then transported by the carrier gas flow to the ICP-MS. The detailed procedures for sample preparation for both analytical techniques were reported below.

3.2.1. Fusion bead method for Major element analysis

- Weighed 1.0000 g ± 0.0009 g of milled sample
- Placed in oven at 110 ℃ for 1 hour to determine H_2O-
- Placed in oven at 1000 ℃ for 1 hour to determine LOI
- Added 10.0000 g ± 0.0009 g Claisse flux and fuse in M4 Claissefluxer for 23 minutes.
- 0.2 g of $NaCO_3$ was added to the mix and the sample+flux+$NaCO_3$ was pre-oxidized at 700 ℃ before fusion and
- The flux type employed was Ultrapure Fused Anhydrous Li-Tetraborate-Li-Metaborate (66.67 % $Li_2B_4O_7$ + 32.83 % $LiBO_2$) and a releasing agent, Li-Iodide (0.5 % LiI).

3.2.2. Pressed pellet method for Trace element analysis

- Weighed 8 g ± 0.05 g of milled powder
- Mixed thoroughly with 3 drops of Mowiol wax binder
- Pressed pellet with pill press to 15 ton pressure and
- Dried in an oven at 100 ℃ for half an hour before analysing.

These analytical methods yielded data for eleven major elements[SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, MnO, CaO, Na_2O, K_2O, Cr_2O_3, P_2O_5] reported as oxide percent by weight and 21 trace elements [Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Co, V, Pb, Th, U, Ti, Cr, Ba, La, Ce, Nd, P] reported as mg/kg (ppm).

3.3 Loss on ignition determination

Loss on Ignition (LOI) is a test used in XRF major element analysis which consists of strongly heating samples of the material at a specified temperature, allowing volatile substances to escape or oxygen is added, until its mass ceases to change. The LOI is made of contributions from the volatile compounds of H_2O^+, OH^-, CO_2, F^-, Cl^-, S; in parts also K^+ and Na^+ (if heated for too long); or alternatively added compoundsO_2 (oxidation, e.g. FeO to Fe_2O_3), laterCO_2 (CaO to $CaCO_3$). In pyro-processing and the mineral industries such as lime, calcined bauxite, refractories or cement manufacturing industry, the loss on ignition of the raw material is roughly equivalent to the loss in mass that it will undergo in a kiln, furnace or smelter.

3.4 Mineralogical analysis

Pulverised sandstone samples were analysed for mineralogical composition by X-ray diffraction (XRD) analysis. A Philips PANalytical instrument with a pw 3830 X-ray generator operated at 40 kV and 25 mA was used. The pulverised samples were oven dried at 100 ℃ for 12 h to remove the adsorbed water. The samples were pressed into rectangular aluminium sample holders using an alcohol wiped spatula and then clipped into the instrument sample holder. The samples were step-scanned from 5 to 85 degrees on 2 theta scale at intervals of 0.02 and counted for 0.5 sec per step.

3.5 Pore water chemistry of the sandstones

The pH of interstitial/pore water was determined using sandstone to water ratio of 1:10. Ten grams of each of the sandstone samples were weighed and put in a beaker and suspended in 100 ml of ultrapure water. The mixture was then agitated thoroughly for 30 min, and allowed to settle for 15 min. The pH, EC, TDS and Eh of the supernatant were recorded. The filterate was analyzed for anions using ion chromatography and cations using inductive coupled plasma optical emission spectroscopy (ICP-OES). Triplicate analysis was carried out in each case.

4. Results and discussion

4.1 Lithologic description

The clastic units at the outcrop section along Auchi-Igarra road are well exposed. The approximately 6.5m thick sandstone sequence (Figures 3 & 4) consists of coarse grained sandstones and clayey materials at the basal part of section A. At the basal part of sections A & B there is prominent brownish, medium to coarse grained and moderately sorted sandstone units. The basal part was laminated with kaolinitic materials at section A indicative of detrital origin in a continental setting. In the middle part, sections A & B consist predominantly of light brown, whitish yellow to pale brown, medium to coarse grained and some moderately sorted sandstone bodies. The upper part of sections A & B compose of pinkish brown, whitish grey to purple reddish, coarse grained, poorly to moderately sorted, clast-supported sandstone. This probably suggests that the sandstone bodies have been deposited in a low energy setting, possibly in a shelf or floodplain (i.e. fluivatile environment). The observed colours variations could be attributed to different cementing materials in the sandstone bodies.

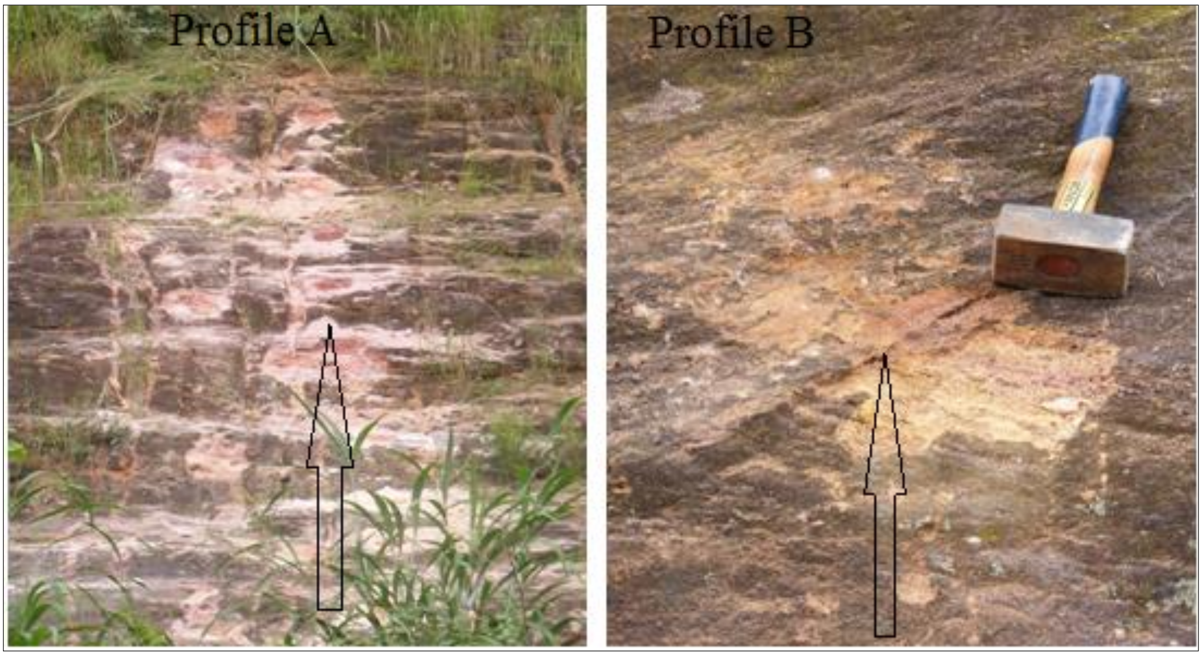
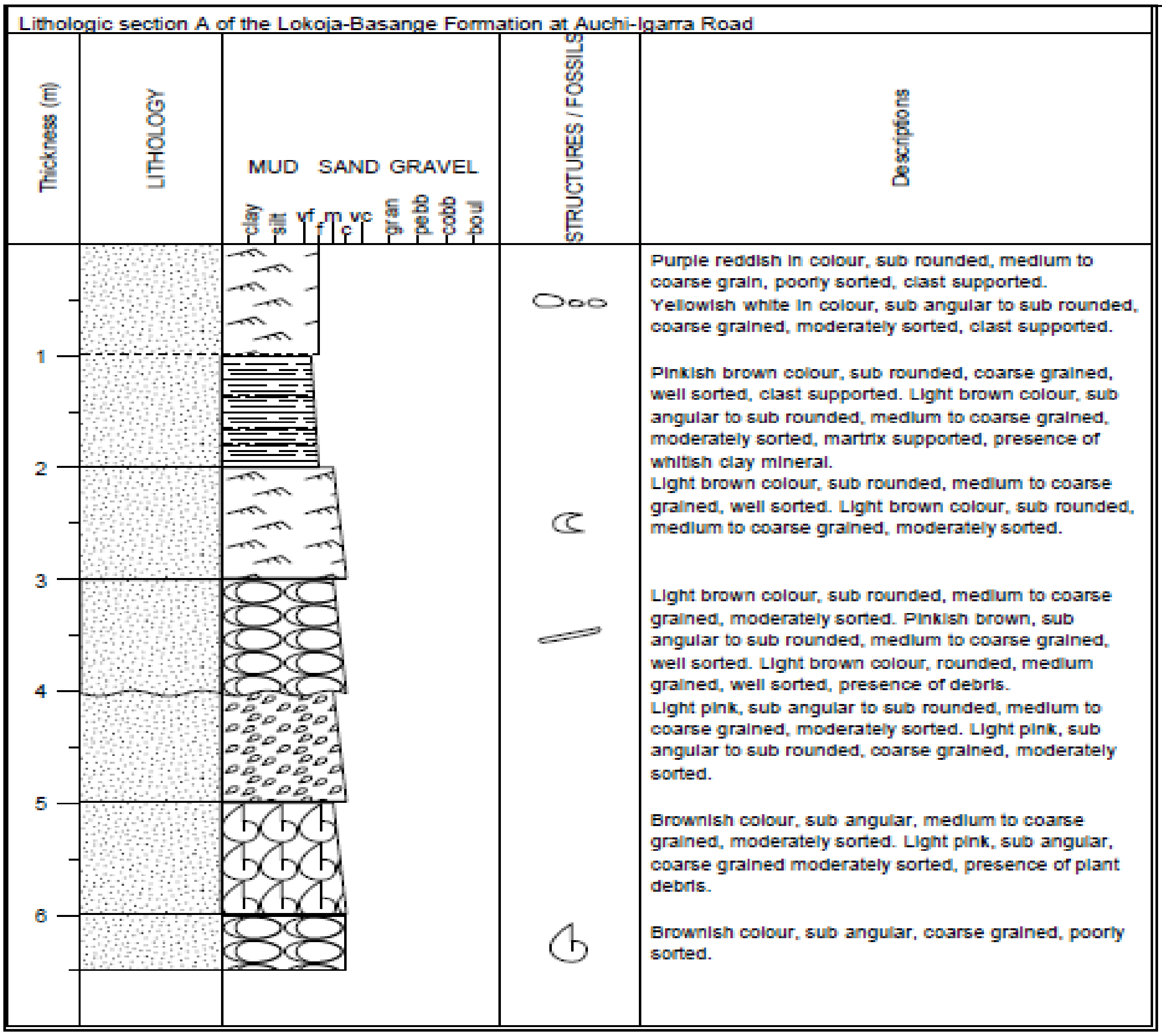


Figure 2. Campanian sandstone of Lokoja-Basange Formation exposed at Auchi-Igarra Road.



Purple reddish in colour, sub rounded, medium to coarse grain, poorly sorted, clast supported. Yellowish white in colour, sub angular to sub rounded, coarse grained, moderately sorted, clast supported.

Pinkish brown colour, sub rounded, coarse grained, well sorted, clast supported. Light brown colour, sub angular to sub rounded, medium to coarse grained, moderately sorted, martrix supported, presence of whitish clay mineral.
Light brown colour, sub rounded, medium to coarse grained, well sorted. Light brown colour, sub rounded, medium to coarse grained, moderately sorted.

Light brown colour, sub rounded, medium to coarse grained, moderately sorted. Pinkish brown, sub angular to sub rounded, medium to coarse grained, well sorted. Light brown colour, rounded, medium grained, well sorted, presence of debris.
Light pink, sub angular to sub rounded, medium to coarse grained, moderately sorted. Light pink, sub angular to sub rounded, coarse grained, moderately sorted.

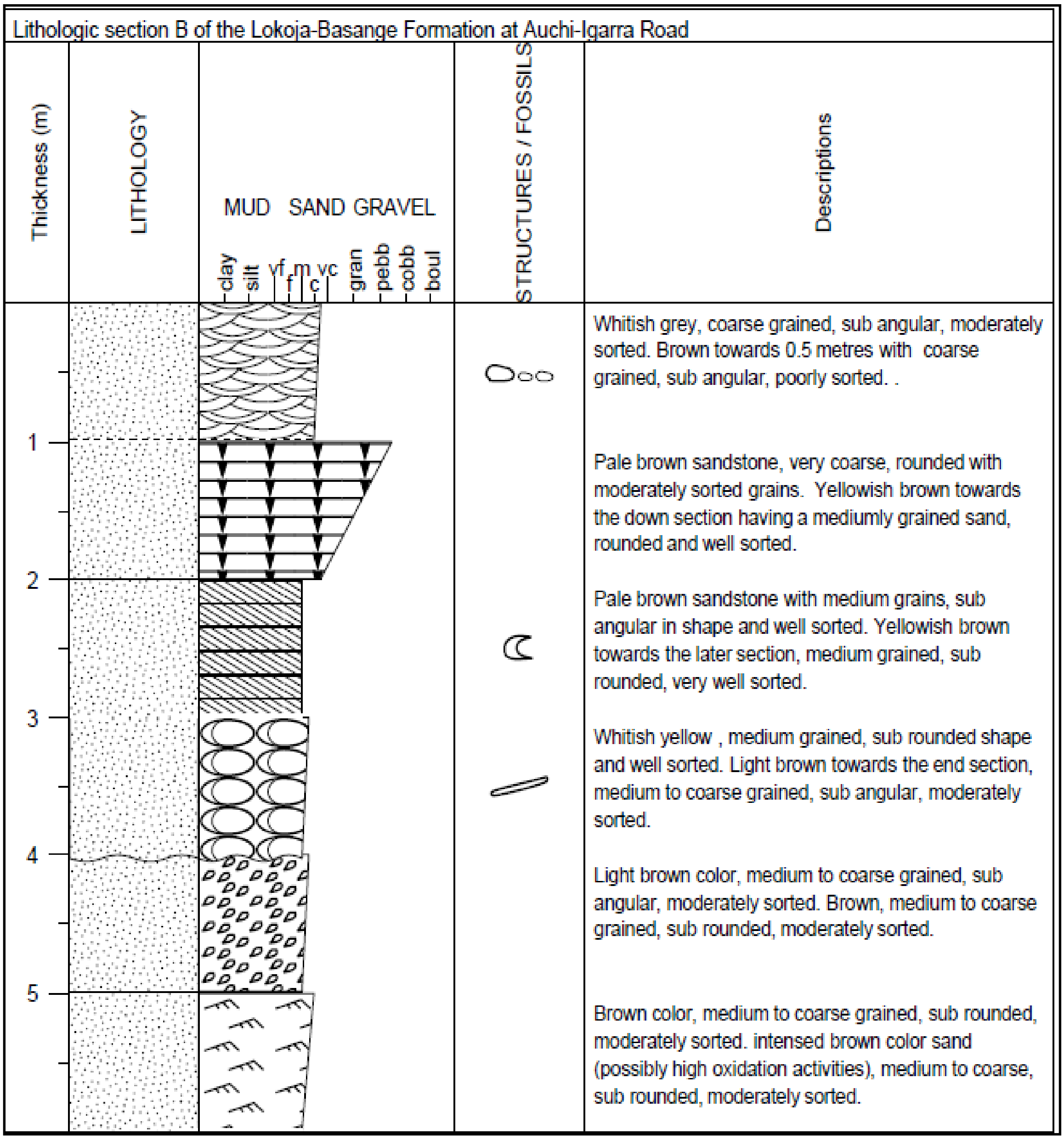
Brownish colour, sub angular, medium to coarse grained, moderately sorted. Light pink, sub angular, coarse grained moderately sorted, presence of plant debris.

Brownish colour, sub angular, coarse grained, poorly sorted.

Figure 3.Lithologic section of profile A.

4.2 Mineralogical Composition

The mineral composition of the Campanian sandstone samples is dominated by quartz and kaolinite, which were found in all samples in both profiles. X-Ray diffraction analyses demonstrate little mineralogical variation between the sandstone samples within specific geochemical intervals. The X-ray diffraction spectra of the first intervals in profile A (0-0.5m and 4-5m) and B (0.5m, 3.5m and 5-5.5m) revealed quartz and kaolinite as the major crystalline minerals with traces of hematite (Figures 5&6). The second specific geochemical interval in profile A (1-3.5m and 5.5-6.5m) and that of B (0, 1-3m and 4-4.5m) showed quartz and kaolinite as the major crystalline mineral phase with minor quantities of grossite and halloysite (Figures 5&6).



Whitish grey, coarse grained, sub angular, moderately sorted. Brown towards 0.5 metres with coarse grained, sub angular, poorly sorted. .

Pale brown sandstone, very coarse, rounded with moderately sorted grains. Yellowish brown towards the down section having a mediumly grained sand, rounded and well sorted.

Pale brown sandstone with medium grains, sub angular in shape and well sorted. Yellowish brown towards the later section, medium grained, sub rounded, very well sorted.

Whitish yellow , medium grained, sub rounded shape and well sorted. Light brown towards the end section, medium to coarse grained, sub angular, moderately sorted.

Light brown color, medium to coarse grained, sub angular, moderately sorted. Brown, medium to coarse grained, sub rounded, moderately sorted.

Brown color, medium to coarse grained, sub rounded, moderately sorted. intensed brown color sand (possibly high oxidation activities), medium to coarse, sub rounded, moderately sorted.

Figure 4.Lithologic section of profile B

Kaolinite is believed to form by weathering or hydrothermal alteration of aluminosilicate minerals. Thus, rocks rich in feldspar commonly weather to kaolinite. Halloysite, which consists of poorly ordered arrangement of kaolinite-like units, with variable amounts of water between the layers, generally between 0.6 to 4H2O per formula unit, and often with a tabular form. Kaolinites are indicators for its detrital origin in continental sediments (Kassim, 2006). Furthermore, Weaver (1960) stated that kaolinite is dominant in sediments of fluviatile environments.

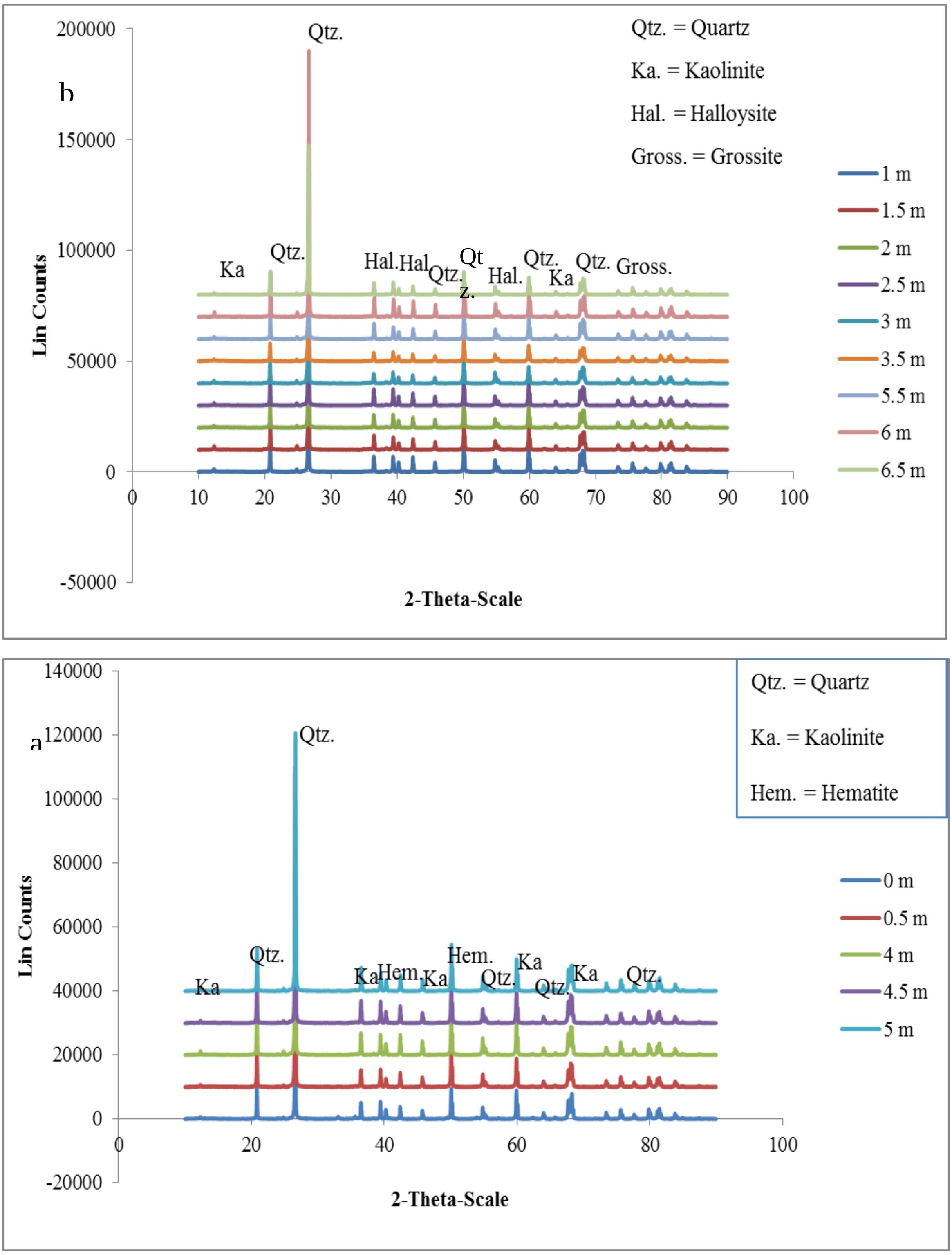


Figure 5a&b. XRD spectra of the sandstone samples taken at profile A.

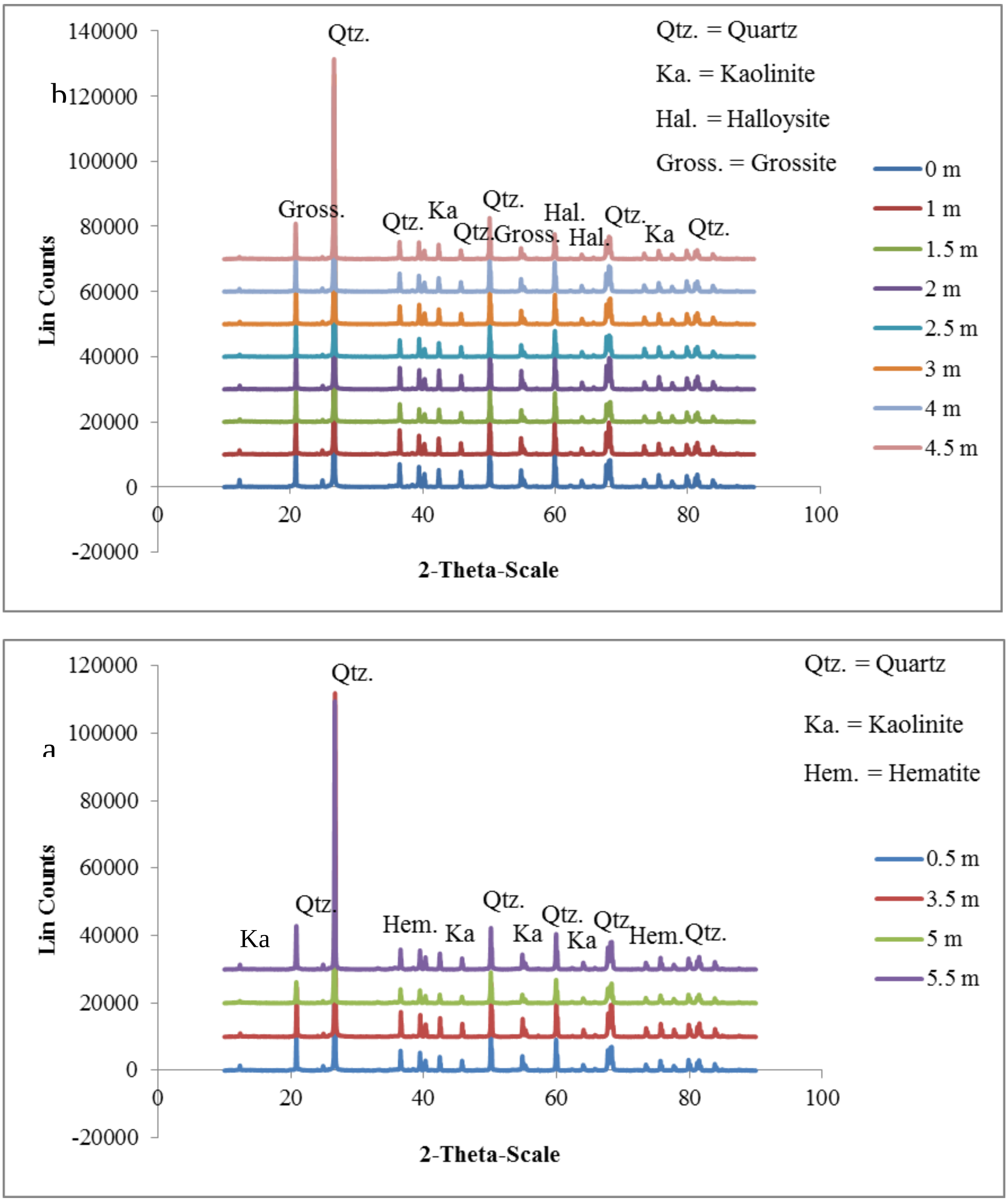


Figure 6a&b. XRD spectra of the sandstone samples taken at profile B.

Kaolinite is known to be concentrated in many near-shore sediments and to decrease in abundance with distance from the shoreline as other clay minerals increase (Parham, 1966). Robert and Kennett (1994) reported that increased kaolinite contents in marine sediments resulted either from increased runoff, which could be caused by sea level falls, or from increased rainfall. Berner and Berner (1996) in their study established that kaolinite is formed under a good drainage system where the water travel-distance was much greater, less rapid flushing of sediments and less removal of silica. Hematite is the oxidation products of weathering of ferrous minerals and constitutes a major source of detrital iron in sediments. During diagenesis limonite may be dehydrated to hematite. In order for this to take place, the original sediment would have to be relatively free from decomposable organic matter so that a high enough oxidation/reduction potential (Eh) can be maintained to stabilize hematite. Since, organic matter is generally abundant in marine sediments; almost all hematite are non-marine (Berner, 1971). Consequently, the presence of hematite in the bottom layers of the shale sequence suggest non-marine environment of deposition.

4.3 pH, EC and TDS of Interstitial water

The average values of pH, EC and TDS of the sandstones in profiles A and B respectively are 6.61 and 6.23; 2.09 μS/cm and 2.66 μS/cm; and13.39 and 17.16ppm correspondingly. Moreover, the average Eh values for profiles A and B is 225.94 and 239.07 respectively. Table 1 shows Pearson's coefficient correlations for all the measured geochemical parameters of the interstitial pore water.

Table 1. Pearson's coefficient correlations for all geochemical parameters measured in the extracted interstitial pore water of the sandstone samples

	Profile A						Profile B					
	pH	Ec	TDS	Eh	Ca	Mg	pH	Ec	TDS	Eh	Ca	Mg
pH	1	0.083	0.085	0.209	0.404	0.082	1	.720**	.719**	-.836**	-0.1	0.423
Ec	0.083	1	1.000**	0.177	.732**	.922**	.720**	1	1.000**	-.509*	-0.3	0.136
TDS	0.085	1.000**	1	0.175	.730**	.920**	.719**	1.000**	1	-.507*	-0.3	0.134
Eh	0.209	0.177	0.175	1	0.108	0.4	-.836**	-.509*	-.507*	1	-0	-.648*
Ca	0.404	.732**	.730**	0.108	1	.651**	-0.059	-0.271	-0.27	-0.047	1	0.456
Mg	0.082	.922**	.920**	0.4	.651**	1	0.423	0.136	0.134	-.648*	0.46	1
Mg/Ca	-0.17	.541*	.540*	0.43	-0.02	.733**	.611*	0.454	0.451	-.756**	-0.1	.775**
Na	-0.04	-0.106	-0.102	-0.02	-0.18	-0.17	0.128	0	0	-0.032	0	0.085
K	-0.28	0.314	0.312	0.179	.481*	0.322	0.273	0.019	0.018	-0.244	-0.2	0.093
K/Na	-0.13	0.317	0.311	-0.07	.509*	0.305	0.232	0.007	0.006	-0.246	-0.2	0.034
F	0.01	0.29	0.292	0.024	.520*	0.218	0.178	-0.009	-0.009	0.089	0.21	-0.33
Cl	0.346	0.153	0.156	0.065	0.364	0.151	-0.278	-0.23	-0.229	0.257	-0.2	-0.22

Correlation is significant at the 0.05 level (1-tailed).

The inverse correlation between Eh and EC, TDS and Mg (at 0.05 significant levels) in the studied samples suggest well oxygenated environment of deposition. Simultaneously, inverse correlation occurs between Eh and pH but at 0.01 significant levels.

4.3 Geochemical classification

The major element concentrations of the Campanian sandstones of Lokoja-Basange Formation are arranged in Tables 2a&b. The concentration of three major oxide groups such as silica and alumina and alkali oxides in conjunction with iron oxides and magnesia were used to classify sandstones. The enrichment of SiO_2 over Al_2O_3 by mechanical and chemical process produces quartz arenites (Orthoquartzites). Silica (quartz) enrichment is a measure of sandstone maturity and is a reflection of the duration and intensity of weathering and destruction of other minerals during transportation. The average values of log SiO_2 / Al_2O_3 in samples taken at certain interval from profiles A (1.46) and profile B (1.43) are less than 1.5 (Tables 2a&b). The values of the log K_2O/Na_2O in the samples from profiles A (-0.15) and B (-0.19) are less than 0 (Tables 2a&b). Furthermore, the average values of the log Fe_2O_3+MgO/Na_2O for all the samples from profiles A (0.21) and B (0.49) are more than 0. The low alkalis values in all the studied samples indicate mature sandstone. The depletion of Na_2O (<1%) in all samples (Tables 2a&b) can be attributed to a relatively smaller amount of Na-rich plagioclase in the sandstone samples.

The enrichment of silica (quartz) over Al_2O_3 (i.e. log $SiO_2/Al_2O_3<1.5$) is a reflection of the duration and intensity of weathering and destruction or dissolution of other minerals during transportation. These indicate that sandstone sediments used in this study had undergone long period of transportation and intense weathering resulting in the destruction of other minerals especially plagioclase and potassium feldspars during transportation.

The geochemical datasets shown in Tables 2a&b and 3 accordingly revealed homogeneous sedimentary formations that are mature lithic arenites including sub-greywacke and protoquartzites.

Table 2a. Major elements concentrations (wt %) for profile A in the Campanian sandstones outcrop of the Lokoja-Basange Formation.

Profile A (Wt %)												
Sample name	**Al_2O_3**	**CaO**	**Cr_2O_3**	**Fe_2O_3**	**K_2O**	**MgO**	**MnO**	**Na_2O**	**P_2O_5**	**SiO_2**	**TiO_2**	**LOI**	**Total**
6.5 m	2.94	0.00	0.00	0.60	0.00	0.05	0.01	0.04	0.01	95.73	0.09	1.12	100.60
6.0 m	3.22	0.00	0.00	0.27	0.00	0.05	0.00	0.03	0.00	96.15	0.12	1.22	101.06
5.5 m	2.73	0.00	0.00	0.40	0.01	0.06	0.00	0.11	0.00	96.27	0.14	1.13	100.85
5.0 m	2.08	0.00	0.00	0.88	0.00	0.05	0.00	0.03	0.01	97.03	0.23	0.90	101.21
4.5 m	1.99	0.00	0.00	0.64	0.00	0.06	0.00	0.04	0.01	96.71	0.19	0.76	100.41
4.0 m	3.50	0.00	0.00	0.61	0.00	0.04	0.00	0.04	0.00	95.02	0.22	1.32	100.75
3.5 m	4.04	0.00	0.00	0.42	0.00	0.05	0.00	0.04	0.00	94.37	0.61	1.58	101.11
3.0 m	5.59	0.00	0.00	0.22	0.00	0.04	0.00	0.05	0.01	92.66	0.12	2.04	100.74
2.5 m	3.72	0.00	0.00	0.32	0.00	0.04	0.00	0.04	0.01	95.44	0.14	1.39	101.10
2.0 m	3.34	0.00	0.00	0.28	0.01	0.04	0.01	0.06	0.01	95.82	0.06	1.26	100.88
1.5 m	7.67	0.00	0.00	1.04	0.03	0.03	0.00	0.06	0.01	89.85	0.37	2.85	101.91
1.0 m	3.86	0.00	0.00	0.33	0.00	0.05	0.00	0.05	0.01	94.48	0.05	1.45	100.27
0.5 m	2.54	0.00	0.00	1.39	0.00	0.05	0.01	0.08	0.01	95.66	0.10	1.06	100.88
0 m	2.49	0.00	0.00	4.55	0.00	0.05	0.01	0.04	0.02	92.70	0.40	1.22	101.48
Min.	1.99	0.00	0.00	0.22	0.00	0.03	0.00	0.03	0.00	89.85	0.05	0.76	
Max.	7.67	0.00	0.00	4.55	0.03	0.06	0.01	0.11	0.02	97.03	0.61	2.85	
Aver.	3.55	0.00	0.00	0.85	0.00	0.05	0.00	0.05	0.01	94.85	0.20	1.38	
Sample name	**CIA**	**CIW**	**MIA**	**PIA**	**Al_2O_3/TiO_2**	**TiO_2/Al_2O_3**	**Na_2O/K_2O**	**SiO_2/Al_2O_3**	**Al_2O_3/SiO_2**	**Fe_2O_3+MgO**	**Log K_2O/Na_2O**	**Log SiO_2/Al_2O_3**	**Log Fe_2O_3+MgO/Na_2O**
6.5 m	98.26	98.26	96.52	98.51	32.54	0.03	0.00	32.54	0.03	0.65	0.00	1.51	0.24
6.0 m	97.04	97.04	94.09	98.97	26.69	0.04	0.00	29.88	0.03	0.32	0.00	1.48	0.25
5.5 m	98.59	98.59	97.19	96.10	19.61	0.05	10.95	35.30	0.03	0.46	-1.04	1.55	-0.03
5.0 m	98.89	99.28	97.77	98.43	9.06	0.11	0.00	46.75	0.02	0.93	0.00	1.67	0.38
4.5 m	98.09	98.38	96.18	97.81	10.44	0.10	0.00	48.54	0.02	0.70	0.00	1.69	0.30
4.0 m	98.81	98.81	97.63	98.76	16.04	0.06	0.00	27.16	0.04	0.65	0.00	1.43	0.18
3.5 m	99.03	99.03	98.06	98.91	6.58	0.15	0.00	23.39	0.04	0.47	0.00	1.37	0.19
3.0 m	98.91	98.91	97.81	99.03	47.37	0.02	0.00	16.57	0.06	0.26	0.00	1.22	-0.03
2.5 m	98.76	98.76	97.51	98.81	26.44	0.04	0.00	25.66	0.04	0.36	0.00	1.41	0.09
2.0 m	97.81	97.81	95.62	98.37	56.16	0.02	5.47	28.67	0.03	0.32	-0.74	1.46	0.02
1.5 m	98.43	98.43	96.85	99.28	20.64	0.05	1.82	11.71	0.09	1.07	-0.26	1.07	0.20
1.0 m	95.77	96.11	91.54	98.59	77.90	0.01	0.00	24.50	0.04	0.38	0.00	1.39	0.09
0.5 m	98.97	98.97	97.94	97.04	25.52	0.04	0.00	37.70	0.03	1.44	0.00	1.58	0.31
0 m	98.51	98.51	97.01	98.26	6.28	0.16	0.00	37.19	0.03	4.60	0.00	1.57	0.75
Min.	95.77	96.11	91.54	96.10	6.28	0.01	0.00	11.71	0.02	0.26	-1.04	1.07	-0.03
Max.	99.03	99.28	98.06	99.28	77.90	0.06	10.95	48.54	0.09	4.60	0.00	1.69	0.75
Aver.	98.28	98.35	96.55	98.35	27.23	0.06	1.30	30.40	0.04	0.90	-0.15	1.46	0.21

Chemical index of alteration (CIA, Nesbitt and Young, 1982), Chemical index of weathering (CIW, Harnois, 1988), Mineralogical index of alteration (MIA.Voicu et al., 1997), Plagioclase index of alteration (PIA, Fedo et al., 1995).

Table 2b. Major elements concentrations (wt %) for profile B in the Campanian sandstones outcrop of the Lokoja-Basange Formation.

.						**Profile B (Wt %)**						
Sample name	**Al_2O_3**	**CaO**	**Cr_2O_3**	**Fe_2O_3**	**K_2O**	**MgO**	**MnO**	**Na_2O**	**P_2O_5**	**SiO_2**	**TiO_2**	**LOI**	**Total**
5.5 m	3.96	0.01	0.00	3.03	0.01	0.05	0.00	0.04	0.04	91.80	0.21	2.09	101.25
5 m	3.80	0.00	0.00	4.92	0.01	0.06	0.01	0.04	0.06	90.24	0.18	1.91	101.22
4.5 m	2.88	0.00	0.00	2.07	0.00	0.05	0.00	0.04	0.02	94.48	0.12	1.32	100.98
4 m	4.12	0.00	0.00	1.12	0.00	0.04	0.00	0.04	0.02	94.28	0.08	1.63	101.33
3.5 m	2.51	0.00	0.00	1.58	0.00	0.06	0.01	0.04	0.02	95.58	0.05	1.23	101.09
3 m	2.87	0.00	0.00	0.58	0.00	0.05	0.00	0.04	0.01	95.83	0.18	1.16	100.72
2.5 m	2.72	0.00	0.00	0.60	0.00	0.05	0.00	0.03	0.01	96.53	0.07	1.07	101.08
2 m	3.30	0.00	0.00	0.95	0.00	0.05	0.01	0.04	0.01	94.95	0.06	1.35	100.72
1.5 m	2.80	0.00	0.01	3.96	0.00	0.06	0.01	0.07	0.04	92.94	0.05	1.55	101.48
1 m	4.39	0.00	0.00	3.09	0.01	0.07	0.01	0.10	0.04	90.95	0.45	1.95	101.06
0.5 m	4.38	0.00	0.00	4.60	0.00	0.05	0.00	0.04	0.06	88.18	1.31	2.31	100.93
0 m	4.60	0.00	0.00	0.70	0.00	0.05	0.00	0.04	0.01	86.90	0.39	1.91	94.60
Min.	2.51	0.00	0.00	0.58	0.00	0.04	0.00	0.03	0.01	86.90	0.05	1.07	
Max.	4.60	0.01	0.01	4.92	0.01	0.07	0.01	0.10	0.06	96.53	1.31	2.31	
Aver.	3.53	0.00	0.00	2.27	0.00	0.05	0.00	0.05	0.03	92.72	0.26	1.62	
Sample name	**CIA**	**CIW**	**MIA**	**PIA**	**Al_2O_3/TiO_2**	**TiO_2/Al_2O_3**	**Na_2O/K_2O**	**SiO_2/Al_2O_3**	**Al_2O_3/SiO_2**	**Fe_2O_3+MgO**	**Log K_2O/Na_2O**	**Log SiO_2/Al_2O_3**	**Log Fe_2O_3+MgO/Na_2O**
5.5 m	99.01	99.01	98.03	98.78	18.73	0.05	4.38	23.18	0.04	3.09	-0.64	1.37	0.63
5 m	99.06	99.06	98.12	98.86	21.41	0.05	4.38	23.76	0.04	4.97	-0.64	1.38	0.80
4.5 m	97.59	97.80	95.17	98.50	24.24	0.04	0.00	32.77	0.03	2.12	0.00	1.52	0.50
4 m	97.70	97.70	95.39	98.95	52.12	0.02	0.00	22.88	0.04	1.16	0.00	1.36	0.31
3.5 m	98.68	98.68	97.36	98.28	50.64	0.02	0.00	38.04	0.03	1.64	0.00	1.58	0.47
3 m	98.80	98.80	97.59	98.48	16.04	0.06	0.00	33.42	0.03	0.63	0.00	1.52	0.23
2.5 m	98.48	98.48	96.97	98.80	39.08	0.03	0.00	35.51	0.03	0.64	0.00	1.55	0.32
2 m	98.28	98.28	96.55	98.68	55.42	0.02	0.00	28.81	0.03	1.00	0.00	1.46	0.32
1.5 m	98.95	98.95	97.89	97.70	56.54	0.02	0.00	33.24	0.03	4.02	0.00	1.52	0.69
1 m	98.50	98.50	96.99	97.80	9.68	0.10	9.85	20.73	0.05	3.16	-0.99	1.32	0.58
0.5 m	98.60	98.86	97.21	99.01	3.36	0.30	0.00	20.13	0.05	4.65	0.00	1.30	0.76
0 m	98.54	98.78	97.08	99.06	11.87	0.08	0.00	18.87	0.05	0.75	0.00	1.28	0.26
Min.	97.59	97.70	95.17	97.70	3.36	0.02	0.00	18.87	0.03	0.63	-0.99	1.28	0.23
Max.	99.06	99.06	98.12	99.06	56.54	0.30	9.85	38.04	0.05	4.97	0.00	1.58	0.80
Aver.	98.52	98.57	97.03	98.57	29.93	0.07	1.55	27.61	0.04	2.32	-0.19	1.43	0.49

Chemical index of alteration (CIA, Nesbitt and Young, 1982), Chemical index of weathering (CIW, Harnois, 1988), Mineralogical index of alteration (MIA.Voicu et al., 1997), Plagioclase index of alteration (PIA, Fedo et al., 1995).

Table 3. Classification of sandstone based on chemical approach (After Blatt et al., 1972; Hebron, 1988; Pettijohn, et al., 1972; Potter, 1978; Akinmosin and Osinowo, 2008; Obiefuna and Orazulike, 2011.

S./ No.	Log of ratio of oxides	Types of sandstone
1.	Log (SiO_2/Al_2O_3) >1.5	Arenites
2.	Log (SiO_2/Al_2O_3) <1 and log (K_2O/Na_2O) < 0	Greywacke
3.	Log (SiO_2/Al_2O_3) <1.5, log (K_2O/Na_2O) > 0 and log (Fe_2O_3+MgO)/(Na_2O+K_2O)	Arkose
4.	Log (SiO_2/Al_2O_3) <1.5, and either log (K_2O/Na_2O) < 0 or log (Fe_2O_3+MgO / Na_2O) > 0	Lithic arenites (including sub-greywacke and protoquartzites

4.4 Weathering in the source area

Weathering indices are useful tools to illustrate weathering profiles and establish the extent of weathering. The weathering indices used to examine the decomposition of unstable mineral are: (1) Chemical Index of Alteration (CIA; Nesbitt and Young, 1982), (2) Chemical Index of Weathering (CIW; Harnois, 1988), and (3) Plagioclase Index of Alteration (PIA; Fedo et al., 1995) (Tables 2a&b). The chemical index of alteration (CIA) defined as CIA = 100 x Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O) and chemical index of weathering (CIW) = (Al_2O_3/(Al_2O_3+CaO+Na_2O)*100 have been established as a general indicator of the degree of weathering in any provenance regions (Nesbitt and Young, 1982; Harnois, 1988; Fedo et al., 1995). In the formula given above, CaO* is the amount of CaO incorporated in the silicate fraction of the studied sandstone samples. Correction for CaO from carbonate contribution was not done for the studied sandstone samples since there was no CO_2 data. Consequently, to compute for CaO* from the silicate fraction, the assumption proposed by Bock et al. (1998) was adopted. In this regard, CaO values were accepted only if CaO ≤ Na_2O; accordingly, when CaO>Na_2O, it was assumed that the concentration of CaO equals that of Na_2O (Bock et al., 1998).

The low CIA values of approximately 50 imply an unweathered upper crust or weak weathering, but high CIA values (i.e. 76-100) indicate intense weathering with a complete removal of alkali and alkaline earth elements and an increase in Al_2O_3 (McLennan, 1993; Fedo et al., 1995; Dupuis et al., 2006). The average CIA values in both profiles A and B are 98.28% and 98.52% respectively while the average CIW values are 98.35% and 98.57% (Tables 2a&b). The variation in CIA values may reflect changes in the proportion of clay minerals in the sandstone samples analyzed. The CIA and CIW values indicate that the sandstone samples have experienced strong chemical weathering (CIA > 90) at the source area.

The extent of weathering at the source area can also be determined by plagioclase index of alteration (PIA; Fedo et al., 1995) calculated by the following equation (molecular proportions): PIA = [(Al_2O_3 - K_2O) / (Al_2O_3 + CaO +Na_2O-K_2O)] *100. The average PIA in profiles A and B is 98.35% and 98.57% respectively and are consistent with the CIA and CIW values in both profiles (Tables 2a&b). The high CIA, PIA, and CIW indices obtained reveal high detrital input dominated by strong chemical weathering, which leads to the formation of clay minerals by hydration and leaching of all major cations, such as Ca^{+2}, K^+, and Na^+ present in feldspar minerals (Gertsch et al., 2011). The mineralogical index of alteration indicates the degree of weathering for each analysed sample, independent of the depth of sampling. The calculation of the mineralogical index of alteration (MIA), according to Voicu et al. (1997) is: MIA = 2*(CIA-50).These ranges of MIA values indicate incipient (0-20%), weak (20-40%), moderate (40-60%), and intense to extreme (60-100%) weathering. The value of 100 % means complete weathering of a primary material into its equivalent weathered product (Voicu and Bardoux, 2002). The average MIA values in both profile A and B are 96.55% and 97.03 % respectively (Tables 2a&b). This is indicative of intense to extreme weathering of mineralogical component of the detrital materials from the source areas. The Al_2O_3, CaO, Na_2O and K_2O constituents in sediments are related with CIA, they show variations between the investigated samples reflecting variable climatic zones or rates of tectonic uplift in source areas. Furthermore the depletion of Na and Ca demonstrates an intense chemical weathering of the source rocks.

4.5 Tectonic setting

The geochemical data obtained from the studied sandstones outcrop along Auchi-Igarra Road indicate both active and passive margin settings. The most favorable discrimination parameters of the Campanian sandstones representing the various tectonic settings is achieved by the plots of Fe_2O_3 + MgO versus TiO_2, Al_2O_3 / SiO_2, K_2O / Na_2O, and Al_2O_3 / (CaO + Na_2O) (Figs. 7a&b). The studied sandstones are plotted in the field of the active and passive continental margin settings. Active continental margin sandstones are dominantly derived from the uplifted basement and reflect the composition of the upper continental crust (Roser and Korch, 1986). Sediments of passive continental margins generally are considered to be mature (Crook, 1974; Schwab, 1975; Sahraeyan and Bahrami, 2012), and are deposited in plate interiors at stable

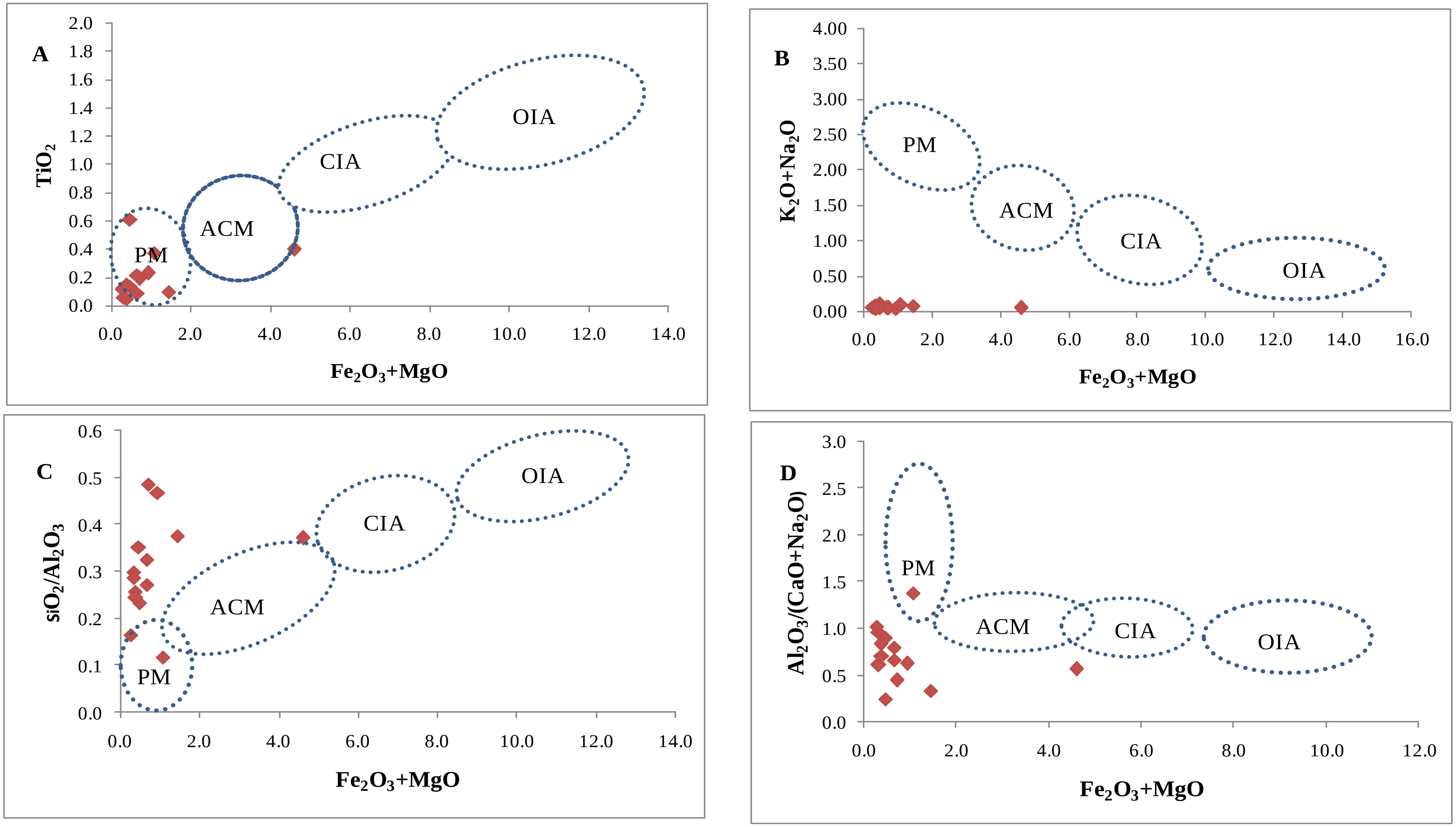


Figure 7a. The tectonic setting discrimination diagrams of samples taken at profile A (after Bhatia, 1983); *OIA: Oceanic island Arc, CIA: continental island Arc, ACM: active continental margin, PM: passive continental margin.*

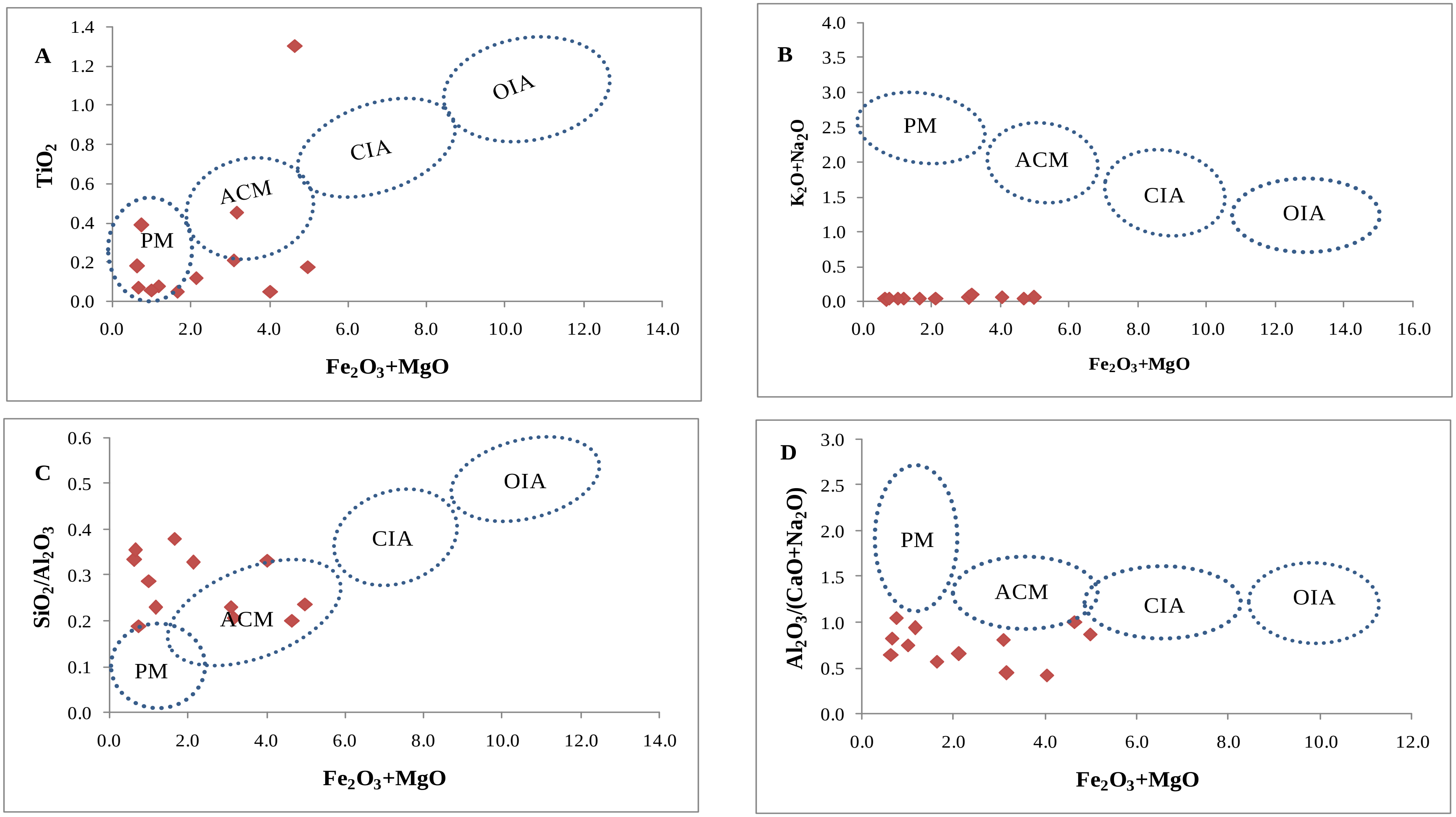


Figure 7b. The tectonic setting discrimination diagrams of samples taken at profile B (after Bhatia, 1983); *OIA: Oceanic island Arc, CIA: continental island Arc, ACM: active continental margin, PM: passive continental margin.*

continental margin or intra-cratonic basins. The average of Na_2O/K_2O ratios in both sandstone profiles A and B is 1.30 and 1.55 respectively implying detrital influx (Sageman and Lyons, 2003). The ratio of Na_2O/K_2O has been used to constrain tectonic settings of sedimentary basins (e.g. Roser & Korsch, 1986) and data from modern deep sea turbidites indicate that sands from volcanically active tectonic settings commonly have $Na_2O/K_2O < 1$, whereas sands from trailing edge margins exhibit ratios larger than 1 (McLennan et al., 1990). However, because of the relatively easy loss of these elements during weathering and loss or gain during diagenesis, one must use alkali elements with caveats (Bock et al., 1989).The high Na_2O/K_2O ratios are attributed to the common absence of K-bearing minerals such as K-feldspar and mica, illite, muscovite, and biotite (McLeann et al., 1983; Nath et al., 2000; Zhang, 2004; Osae et al., 2006). The average ratios of Ti/Zr for profile A and B in the sandstones are 6.95 and 7.70 respectively (Tables 4a&b). The mean ratio of Ti/Zr suggests active and passive continental margin settings for the sandstones (Bhatia and Crook, 1986).

4.6 Provenance

Table 2a&b shows the major element concentration of sandstone exposure samples taken from profile A and B. In the studied sandstone samples, the average Al_2O_3/TiO_2 ratios for the profiles A and B is 27.23 and 29.93 respectively (Tables 3a&b). Al_2O_3/TiO_2 ratios of most clastic rocks are essentially used to infer the source rock compositions, because the Al_2O_3/TiO_2 ratio increases from 3 to 8 for mafic igneous rocks, from 8 to 21 for intermediate rocks, and from 21 to 70 for felsic igneous rocks (Hayashi et al., 1997). Accordingly, the average Al_2O_3/TiO_2 ratios obtained suggest felsic igneous rocks as the probable source rocks for the studied Campanian sandstone samples.

The studied Campanian sandstones have extreme SiO_2 contents in both profiles A and B averaging 94.85wt% and 92.72 wt% respectively but, as expected; the sandstones have higher SiO_2 and correspondingly lower Al_2O_3. The average of SiO_2/Al_2O_3 ratios of the Campanian sandstone in both profiles A and B is 30.40 and 27.61 respectively show detrital influx dominated by large extent of weathering. Generally, the low average values of Al_2O_3/SiO_2 ratio indicate quartz enrichment in the both profiles. The average of Na_2O/K_2O ratios of the studied sandstone samples in both profiles A and B is 1.30 and 1.55 respectively. This literally suggests the felsic igneous rocks for the studied sandstones. The large quantity of alkalis (Na_2O and K_2O) characterizes immature sandstones such as Arkoses and greywackes whereas the ratios of Na_2O/K_2O could be used to establish both the provenance and diagenesis of sandstone deposit (Akinmosin and Osinowo, 2008; Ibe and Akaolisa, 2010).

Trace elements such as Cr, Ni, Co, and V have been used to determine mafic and ultramafic sources (Wronkiewicz and Condie, 1987; Huntsman-Mapila et al., 2005). The average concentrations of the followings trace elements in profile A and B respectively are: Cr, 12.62ppm and 12.45ppm; Co, 202.77ppm and 176.09ppm; and V, 27.15ppm and 40.45ppm (Tables 4a&b). Trace elements such as Ba, Sr and Y showed lower concentration in the sandstones. Nevertheless, the average concentration of Zr in profile A and B are 172.85ppm and 203.27ppm respectively (Tables 4a&b). The lower concentrations of Cr, Co, Ni and Cr and higher concentration of Zr observed in the sandstones suggest felsic source rock. Felsic source rocks usually contain lower concentrations of Cr, Co, Ni, and V and higher concentrations of Ba, Sr, Y, and Zr than mafic and intermediate source rocks (Wronkiewicz and Condie, 1987; Spalletti et al., 2008). Besides, the relatively higher concentrations of La and Ce in the sandstones (Tables 4a&b) also suggest felsic source rock. REE and Th abundances are higher in felsic than in mafic igneous source rocks and in their weathered products, whereas Co, Sc, and Cr are more concentrated in mafic than in felsic igneous rocks and in their weathered products (Armstrong-Altrin et al., 2004).

Ratios such as Eu/Eu*, (La/ Lu)cn, La/Sc, Th/Sc, La/Co, Th/Co, and Cr/Th are significantly different in mafic and felsic source rocks and can therefore provide information about the provenance of sedimentary rocks (Cullers et al. 1988; Wronkiewicz and Condie 1989; Condie and Wronkiewicz 1990; Cullers 1994). Accordingly, the higher ratios of La/Y and La/Th and corresponding lower ratios of La/Co and Th/Co in both profiles A and B (Tables 4a&b) indicate felsic source rock. The lower ratios of Ba/Sr, Cr/Zr, Ti/Zr and higher ratio of Zr/Y in the sandstones (Tables 4a&b) probably suggest felsic source rock. The existence of huge complexes of mafic/ultramafic rocks in the source region is most unlikely.

4.7 Paleo-redox condition

The average Cu/Zn ratio in the profiles A and B of the studied sandstones is 0.14 and 0.20 respectively (Tables 4a&b). According to Hallberg (1976) high Cu/Zn ratios indicate reducing depositional conditions, while low Cu/Zn ratios suggest oxidizing conditions. Therefore, the low Cu/Zn ratios in these sandstone

Table 4a. Trace elements concentrations (ppm) for profile A in the Campanian sandstones outcrop of the Lokoja-Basange Formation.

Profile A (ppm)																	
Sample name	**Ni**	**Cu**	**Zn**	**Ga**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Pb**	**Th**	**U**	**Ti**	**V**	**Cr**	**La**	**Ce**
6.5m	*BD*	6.00	9.00	2.00	*BD*	10.00	3.00	124.00	4.00	133.0	*BD*	*BD*	691.00	15.00	21.00	10.00	*BD*
6.0m	*BD*	*BD*	9.00	2.00	*BD*	9.00	2.00	130.00	5.00	132.0	1.00	*BD*	886.00	19.00	5.00	14.00	*BD*
5.5m	*BD*	1.00	10.00	3.00	*BD*	10.00	3.00	228.00	5.00	133.0	3.00	*BD*	949.00	18.00	12.00	10.00	*BD*
5.0m	*BD*	1.00	10.00	3.00	*BD*	10.00	3.00	176.00	5.00	134.0	4.00	*BD*	1459.00	31.00	13.00	12.00	14.00
4.5m	*BD*	1.00	10.00	2.00	*BD*	9.00	3.00	193.00	5.00	134.0	2.00	*BD*	1232.00	27.00	14.00	11.00	0.00
4.0m	*BD*	*BD*	9.00	3.00	1.00	10.00	5.00	292.00	6.00	136.0	8.00	*BD*	1475.00	32.00	5.00	22.00	4.00
3.5m	*BD*	1.00	9.00	5.00	1.00	11.00	6.00	415.00	12.00	137.0	7.00	*BD*	4024.00	85.00	9.00	6.00	28.00
3.0m	*BD*	*BD*	9.00	5.00	*BD*	10.00	2.00	100.00	4.00	132.0	1.00	*BD*	837.00	18.00	16.00	16.00	6.00
2.5m	*BD*	0.00	9.00	3.00	*BD*	10.00	2.00	132.00	5.00	134.0	2.00	*BD*	919.00	21.00	12.00	1.00	*BD*
2.0m	*BD*	*BD*	9.00	4.00	*BD*	10.00	2.00	82.00	3.00	134.0	*BD*	*BD*	406.00	9.00	6.00	5.00	1.00
1.0m	*BD*	*BD*	10.00	3.00	*BD*	10.00	2.00	69.00	4.00	135.0	0.00	*BD*	379.00	8.00	21.00	19.00	*BD*
0.5m	*BD*	0.00	12.00	3.00	1.00	9.00	1.00	108.00	4.00	134.0	2.00	*BD*	668.00	15.00	13.00	10.00	*BD*
0m	2.00	1.00	15.00	2.00	2.00	10.00	2.00	198.00	7.00	142.0	7.00	*BD*	2459.00	55.00	17.00	16.00	2.00
Min.	2.00	0.00	9.00	2.00	1.00	9.00	1.00	69.00	3.00	132.00	0.00	0.00	379.00	8.00	5.00	1.00	0.00
Max.	2.00	6.00	15.00	5.00	2.00	11.00	6.00	415.00	12.00	142.00	8.00	0.00	4024.00	85.00	21.00	22.00	28.00
Aver.	2.00	1.38	10.00	3.08	1.25	9.85	2.77	172.85	5.31	134.62	3.36	*BD*	1260.31	27.15	12.62	11.69	7.86

Profile A (ppm)																
Sample name	**Nd**	**P**	**Co**	**Ba**	**TiO_2/Zr**	**Ba/Sr**	**Zr/Y**	**Cr/Zr**	**Ti/Zr**	**Cu/Zn**	**Cr/Th**	**V/Cr**	**Th/Co**	**La/Co**	**La/Y**	**La/Th**
6.5m	16.00	55.00	189.00	3.00	7.29	0.30	41.33	0.17	5.57	0.67	*BD*	0.71	0.00	0.05	3.33	0.00
6.0m	12.00	39.00	167.00	24.00	9.27	2.67	65.00	0.04	6.82	*BD*	5.00	3.80	0.01	0.08	7.00	14.00
5.5m	20.00	37.00	202.00	9.00	6.10	0.90	76.00	0.05	4.16	0.10	4.00	1.50	0.01	0.05	3.33	3.333
5.0m	26.00	50.00	219.00	15.00	13.01	1.50	58.67	0.07	8.29	0.10	3.25	2.38	0.02	0.05	4.00	3.00
4.5m	23.00	47.00	201.00	17.00	9.89	1.89	64.33	0.07	6.38	0.10	7.00	1.93	0.01	0.05	3.67	5.50
4.0m	12.00	58.00	188.00	13.00	7.47	1.30	58.40	0.02	5.05	*BD*	0.63	6.40	0.04	0.12	4.40	2.75
3.5m	24.00	40.00	196.00	32.00	14.77	2.91	69.17	0.02	9.70	0.11	1.29	9.44	0.04	0.03	1.00	0.86
3.0m	29.00	41.00	163.00	8.00	11.81	0.80	50.00	0.16	8.37	*BD*	16.00	1.13	0.01	0.10	8.00	16.00
2.5m	16.00	40.00	226.00	6.00	10.66	0.60	66.00	0.09	6.96	0.00	6.00	1.75	0.01	0.00	0.50	0.50
2.0m	20.00	35.00	212.00	2.00	7.26	0.20	41.00	0.07	4.95	*BD*	*BD*	1.50	0.00	0.02	2.50	0.00
1.0m	15.00	42.00	226.00	8.00	7.17	0.80	34.50	0.30	5.49	*BD*	*BD*	0.38	0.00	0.08	9.50	0.00
0.5m	14.00	61.00	225.00	15.00	9.20	1.67	108.00	0.12	6.19	0.00	6.50	1.15	0.01	0.04	10.00	5.00
0m	26.00	119.00	222.00	14.00	20.05	1.40	99.00	0.09	12.42	0.07	2.43	3.24	0.03	0.07	8.00	2.29
Min.	12.00	35.00	163.00	2.00	6.10	0.20	34.5	0.02	4.16	0.00	0.63	0.38	0.00	0.00	0.50	0.00
Max.	29.00	119.00	226.00	32.00	20.05	2.67	108	0.30	12.42	0.67	16.00	9.44	0.04	0.12	10.00	16.00
Aver.	19.46	51.08	202.77	12.77	10.30	1.30	63.95	0.10	6.95	0.14	5.21	2.72	0.01	0.06	5.02	4.09

Table 4b. Trace elements concentrations (ppm) for profile A in the Campanian sandstones outcrop of the Lokoja-Basange Formation.

Profile B (ppm)																
Sample name	**Ni**	**Cu**	**Zn**	**Ga**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**	**Pb**	**Th**	**U**	**Ti**	**V**	**Cr**	**La**	**Ce**
5.5m	*BD*	2.00	13.00	4.00	1.00	11.00	2.00	229.00	6.00	135.00	5.00	*BD*	1460.00	30.00	22.00	18.00	0.00
5.0m	*BD*	11.00	22.00	3.00	*BD*	13.00	4.00	202.00	5.00	146.00	4.00	*BD*	1192.00	26.00	21.00	23.00	15.00
4.0m	*BD*	1.00	13.00	3.00	*BD*	10.00	3.00	89.00	4.00	136.00	0.00	*BD*	560.00	12.00	13.00	8.00	*BD*
3.5m	*BD*	4.00	15.00	3.00	*BD*	10.00	2.00	71.00	4.00	136.00	0.00	*BD*	328.00	7.00	13.00	8.00	*BD*
3.0m	*BD*	*BD*	11.00	4.00	*BD*	10.00	3.00	139.00	5.00	133.00	1.00	*BD*	1133.00	24.00	0.00	6.00	*BD*
2.5m	*BD*	2.00	15.00	3.00	*BD*	10.00	3.00	135.00	5.00	136.00	0.00	*BD*	843.00	19.00	11.00	7.00	13.00
2.0m	*BD*	*BD*	14.00	2.00	*BD*	11.00	2.00	83.00	4.00	135.00	3.00	*BD*	456.00	11.00	12.00	7.00	*BD*
1.5m	*BD*	3.00	24.00	1.00	*BD*	10.00	2.00	68.00	3.00	140.00	0.00	*BD*	308.00	6.00	12.00	13.00	*BD*
1.0m	*BD*	*BD*	14.00	2.00	1.00	12.00	9.00	337.00	9.00	143.00	16.00	*BD*	3038.00	64.00	10.00	40.00	53.00
0.5m	3.00	4.00	24.00	5.00	4.00	13.00	15.00	706.00	22.00	163.00	33.00	6.00	8387.00	181.00	9.00	55.00	92.00
0m	*BD*	2.00	10.00	5.00	*BD*	10.00	6.00	177.00	9.00	140.00	4.00	*BD*	2866.00	65.00	14.00	14.00	4.00
Min.	3.00	1.00	10.00	1.00	1.00	10.00	2.00	68.00	3.00	133.00	0.00	6.00	308.00	6.00	0.00	6.00	0.00
Max.	3.00	11.00	24.00	5.00	4.00	13.00	15.00	706.00	22.00	163.00	33.00	6.00	8387.00	181.00	22.00	55.00	92.00
Aver.	3.00	3.63	15.91	3.18	2.00	10.91	4.64	203.27	6.91	140.27	6.00	6.00	1870.09	40.45	12.45	18.09	29.50

Profile B (ppm)															
Sample name	**Nd**	**P**	**Co**	**Ba**	**TiO_2/Zr**	**Ba/Sr**	**Zr/Y**	**Cr/Zr**	**Ti/Zr**	**Cu/Zn**	**Cr/Th**	**V/Cr**	**Th/Co**	**La/Co**	**La/Y**	**La/Th**
5.5m	22.00	218.00	174.00	17.00	17.05	1.55	114.50	0.10	6.38	0.15	4.40	1.36	0.03	0.10	9.00	3.60
5.0m	17.00	323.00	155.00	23.00	13.64	1.77	50.50	0.10	5.90	0.50	5.25	1.24	0.03	0.15	5.75	5.75
4.0m	21.00	70.00	189.00	*BD*	5.22	0.00	29.67	0.15	6.29	0.08	0.00	0.92	0.00	0.04	2.67	0.00
3.5m	14.00	90.00	236.00	4.00	4.49	0.40	35.50	0.18	4.62	0.27	0.00	0.54	0.00	0.03	4.00	0.00
3.0m	19.00	59.00	212.00	15.00	2.57	1.50	46.33	0.00	8.15	*BD*	0.00	0.00	0.00	0.03	2.00	6.00
2.5m	28.00	133.00	202.00	8.00	6.12	0.80	45.00	0.08	6.24	0.13	*BD*	1.73	0.00	0.03	2.33	0.00
2.0m	14.00	89.00	174.00	24.00	1.68	2.18	41.50	0.14	5.49	*BD*	4.00	0.92	0.02	0.04	3.50	2.33
1.5m	9.00	197.00	169.00	14.00	5.95	1.40	34.00	0.18	4.53	0.13	*BD*	0.50	0.00	0.08	6.50	0.00
1.0m	33.00	249.00	141.00	18.00	3.75	1.50	37.44	0.03	9.01	*BD*	0.63	6.40	0.11	0.28	4.44	2.50
0.5m	37.00	398.00	147.00	57.00	55.25	4.38	47.07	0.01	11.88	0.17	0.27	20.11	0.22	0.37	3.67	1.67
0m	24.00	57.00	138.00	30.00	189.15	3.00	29.50	0.08	16.19	0.20	3.50	4.64	0.03	0.10	2.33	3.50
Min.	9.00	57.00	138.00	4.00	1.68	0.00	29.50	0.00	4.53	0.08	0.00	0.00	0.00	0.03	2.00	0.00
Max.	37.00	398.00	236.00	57.00	189.15	4.38	114.50	0.18	16.19	0.50	5.25	20.11	0.22	0.37	9.00	6.00
Aver.	21.64	171.18	176.09	21.00	27.72	1.68	46.46	0.10	7.70	0.20	2.01	3.49	0.04	0.12	4.20	2.30

samples (Tables 4a&b) suggest that the studied sandstone was deposited under oxidizing conditions. According to Jones and Manning (1994), the V/Cr ratios above 2 indicate anoxic conditions, whereas values below 2 suggest more oxidizing conditions. The average V/Cr ratio in the studied sandstones is 2.72 and 3.49 respectively (Tables 4a&b). The slight rise in V/Cr ratios could be attributed to Cr concentrations which are highly influenced by detrital input into marine sediments, which therefore significantly affect paleo-redox interpretations (Jacobs et al., 1985; Jacobs et al., 1987).

5. Summary and conclusions

The composition, provenance, weathering, tectonic setting and redox proxy of the Campanian sandstone of Lokoja-Basange Formation, Middle Niger (Lokoja sub-basin) southern Nigeria has been assessed using integrated mineralogical, geochemical and pore water chemistry approach. The medium to coarse grained clastic units exposed along Auchi-Igarra Road consists of sandstone intercalated with kaolinitic clay materials at the basal part. The sandstone bodies are moderate to poorly sorted suggesting deposition in a low energy setting, possibly in a shelf or floodplain. The colour variations of the sandstone bodies are indication of differences in the cementing materials. Two specific geochemical intervals were established based on the mineralogical composition. The first interval revealed quartz and kaolinite as major crystalline minerals with traces of hematite. The second geochemical interval showed quartz and kaolinite as the major crystalline minerals with minor quantities of grossite and halloysite. The geochemical datasets revealed mature lithic arenites including sub-greywacke and protoquartzites clastic sediments. The inverse correlation between Eh and EC, TDS and Mg (at 0.05 significant levels) in the studied sandstone samples suggest well oxygenated environment of deposition. The high CIA, PIA, and CIW indices obtained revealed high detrital input dominated by strong chemical weathering. This ultimately led to the formation of clay minerals by hydration and leaching of all major cations, such as Ca^{2+}, K^+, and Na^+, present in feldspar minerals. The average MIA values in both profile A and B are indicative of intense to extreme weathering of mineralogical component of the detrital materials from the source areas. The studied Campanian sandstones of Lokoja-Basange Formation are plotted in the field of the active and passive continental margin settings. The mean ratio of Ti/Zr also suggests active and passive continental margin settings. Moreover, the higher ratios of La/Y and La/Th and corresponding lower ratios of La/Co and Th/Co indicate felsic source rock. Furthermore, the lower ratios of Ba/Sr, Cr/Zr, Ti/Zr and higher ratio of Zr/Y probably suggest felsic source rock. The low Cu/Zn ratios of studied sandstone samples suggest deposition under oxidizing conditions.

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