

Provenance of the Campanian-Maastrichtian Shales, Anambra Basin: Evidence from Clay Mineralogy

Shirley Onyinye Odunze-Akasiugwu
Department of Geology, Faculty of Physical Sciences, Chukwuemeka Odumegwu Ojukwu University
P.M.B 02, Uli, Anambra State, Nigeria

Abstract

The origin, formation and history of the Campanian-Maastrichtian Anambra basin-fill are issues of considerable interest and importance especially in the reconstruction of the basin evolution and assessment of the hydrocarbon potential. Previous sandstone petrographic studies point to the easterly Cameroon Precambrian basement complex as the primary source of the Anambra Basin detritus and ascribe the high compositional maturity index to intense chemical weathering both at source and during transport. The provenance interpretation presented in this work is based on results of mineralogical analysis of the mud rocks sampled at regular intervals of the Campanian-Maastrichtian succession and analyzed for clay minerals, using X-ray diffractometer technique. The results show that quartz and kaolinite are the most abundant minerals in the mud rocks. Illite is resident in lesser quantities in all samples, and some samples also contain appreciable amounts of smectites and mixed layer (illite/smectites) clays. The relative abundance and distribution of clay minerals in the shales analyzed in this work suggests primary derivation from an igneous complex dominated by intermediate to basic rocks.Trends in the quartz, clay mineral ratios and the kaolinite abundance strongly suggest derivation from the Precambrian basement complex of the Cameroon and the arkosic pre-Campanian strata of the Abakaliki Anticlinorium, and supply into the Anambra Basin by rivers. This interpretation is consistent with views held by earlier workers that erosion of the pre-Campanian sediments and weathering of the adjoining basement blocks sourced the kaolinite-rich mud rocks of the Anambra Basin. The result of this research represents a useful contribution to the on-going review of the sedimentology and hydrocarbon potentials of the Anambra Basin.

Keywords: Provenance; Campanian-Maastrichtian; Anambra Basin; Clay Mineralogy

1. Introduction

The Anambra basin of the southern Benue Trough (Fig. 1) is bounded to the south, north and West by Niger Delta and the Precambrian basement complexes of Jos, and Ibadan massifs. It is separated from the Cameroon massif by the Abakaliki basin which comprises sandstones, shales and limestone of the Asu River Group, Ezeaku Group and the Awgu Group. The basement complexes comprise migmatitic and granitic gneisses, quartzites and metasedimentary schists. The origin, formation, and history of the Anambra Basin are a matter of considerable interest and importance especially in the reconstruction of the basin evolution and assessment of the hydrocarbon potential. Several workers have discussed the depositional history of the Anambra basin-fill. Hoque (1977), and Hoque and Ezepue (1977) favor the interpretation that recognizes the eastern granitic basement complex of the Cameroon massif as the primary source of most of the Anambra Basin detritus. They ascribed the high compositional maturity index to intense chemical weathering both at source and during transport. Amajor (1987) and Obi (2000) recognize the sands as second cycle detritus derived from the elevated Abakaliki Anticlinorium and deposited in environments that ranged from shallow marine to marginal marine. Obi (2000) noted an

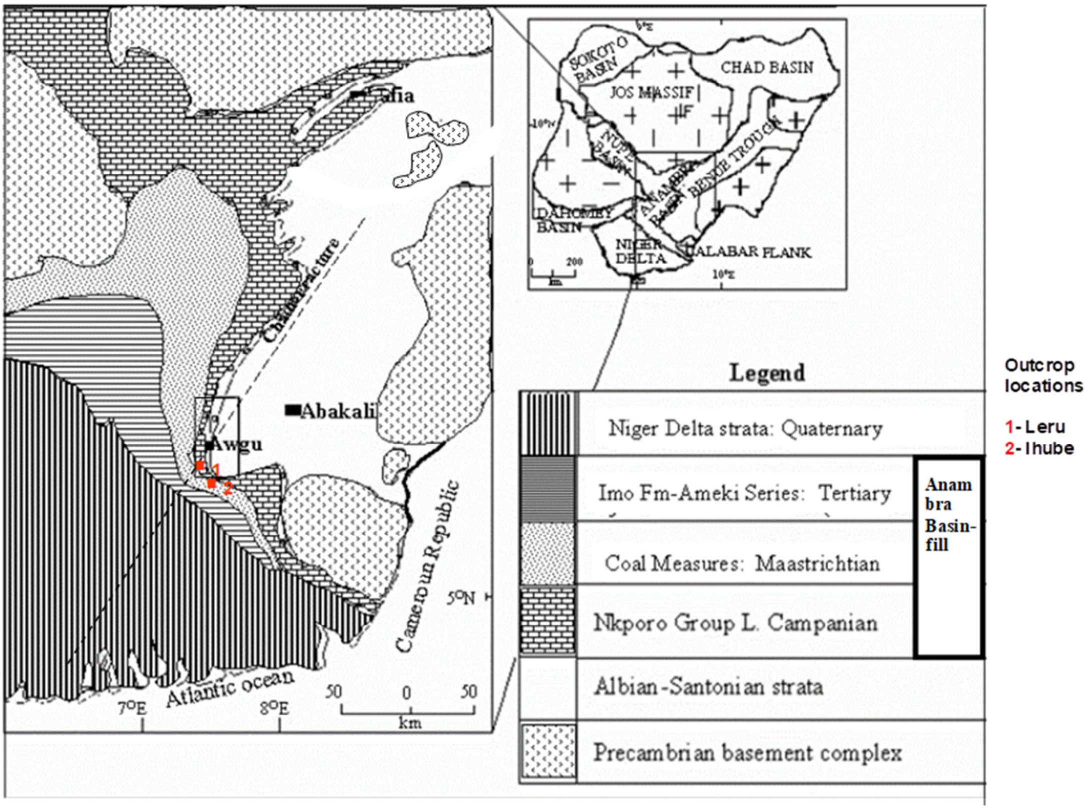

Figure. 1. Geological map of southeastern Nigeria showing the distribution of the Campanian-Maastrichtian Formations (Obi, et al, 2005). Samples were collected from the Leru (location 1) and Ihube (location 2) outcrops.

up-section change from metamorphic to sedimentary petrofacies within the Campanian-Maastrichtian Anambra Basin succession and interpreted this to be the result of reactivation of the Abakaliki uplift and exposure of the flanks of the fold structure to erosion. The abundance and general up-section increase in sedimentary rock fragments in the Anambra Basin, is interpreted as evidence that the basin subsided episodically during the filling history. Deposits proximal to basin-margin structures were uplifted, eroded, and incorporated in younger deposits. The provenance interpretation presented in this work is based on clay mineralogy of the Anambra basin-fill.

2. Geologic Setting

The study area lies within the Anambra basin of Lower Benue Trough. Nigeria's Benue Trough, located at the Gulf of Guinea re-entrant on the west coast of Africa is an 80-90km wide fault bounded depression containing up to 500m of deformed cretaceous sedimentary and volcanic rocks (Grant, 1971). There are several theories that relate to the evolution of the Benue Trough, these includes works done by Grant (1971), Nwachukwu (1972), Burke and Dewey, (1973) and Olade (1975), etc.

Generally the Benue Trough is divided into upper, middle and lower Benue. The lower Benue Trough is situated at the southern end of Nigeria. The major components of the lower Benue-Trough or Southeastern Nigeria sedimentary Basin are the Abakaliki – Benue Trough, the Anambra Basin and the Afikpo Syncline. Tectonic phase or eperogenic movement controlled the sedimentation history of these sub-basin resulting in various transgress - regressive cycles. The transgressive-regressive cycles of the first tectonic phase led to sedimentation within the Abakaliki-Benue Trough. The second tectonic phase deformed and uplifted the trough resulting into two depressions which are the Anambra Basin and the Afikpo Syncline. They flank the trough respectively to the North West and to the South West. The two depressions then became the main foci of the deposition during the Campanian to Paleocene. The stratigraphic evolution of the southern Nigerian Sedimentary basin complex during the Campanian-Eocene period was controlled by episode asymmetrical subsidence along the landward extension of the Atlantic chain fracture associated with the initial opening of the Benue Trough (Ojoh; 1992, Obi et al; 2001 and Obi and Okogbue; 2004). Occurring at a period when the Cameroon Volcanic line was initiated (Burke, 1996), this phase of vertical movement is generally believed to be in isostatic response to the thermal relaxation of the lithosphere (Binks and Fairhead, 1992; Burke, 1996).

Seven depositional cycles of over 4000m composite thickness and comprises shallow marine marginal marine Nkporo Group (Campanian – Maastrichtian), Mamu Formation and Ajali Sandstone (Maastrichtian), Nsukka Formation (Maastrichtian – Palaeocene), Imo Formation (Palaeocene), Ameki Formation (Eocene) and the Ogwashi-Asaba Formation (Oligocene); are preserved in the basin (Oboh- Ikwunobe et al, 2005).

3. Methodology

Samples of the Nkporo Group and the Mamu Formation were collected from selected intervals of the Leru section whereas the Nsukka Formation was sampled at Ihube (Fig. 2), where the formations are well exposed.

Samples were analyzed for clay minerals using X-ray diffractometer technique. The samples were air-dried, saturated with ethylene glycol (EG), and heated to 500^0C. X-ray diffraction patterns were obtained with a DIANO 2100E using a Cu tube operated at 50kv and 40ma.

Clay mineralogy was approximated by measuring the most intense X-ray diffraction peaks of each mineral. Peak positions and intensities were measured with the DIANO diffract AT software at the Nigerian National Petroleum Corporation (N.N.P.C) laboratory, Port Harcourt.

4. Results

Table 1 summarizes the distribution of clay minerals in the shale samples, and Figure 3 shows a typical x-ray diffraction pattern of the clay minerals.

4.1 Texture

The shales exhibit both homogenous and oriented textures. Shales at the basal part of the Nkporo, Mamu and Nsukka Formations exhibit typical oriented textures. The rocks are exceptionally fissile. Fissility in such "paper–shales" is attributable to the abundance of straight-chain aliphatic hydrocarbons whose terminal hydrogen atoms have been replaced by reactive group. These molecules are thus made polar, and will orient themselves between clay flakes (Blatt et al., 1972).

The shales which generally exhibit various shades of lighter colours (from pink to light grey, possibly reflecting more aerated environments) are more homogenous, commonly bioturbated and cryptocrystalline. Fissility is generally lacking, due to the burrowing activities of organisms that churn the mud and disorient the clays.

4.2 Composition

Kaolinite and quartz are the most abundant minerals present in the shale samples. Kaolinite content fluctuates between 73.8% in the Nkporo Shale and 92.7%in the Enugu Shale, with abundance maxima occurring consistently down dip. Quartz percentages decrease progressively down dip,averaging 62.5%, 49.0%, 63% and 38% in the Nkporo, Enugu, Mamu, and Nsukka Formations respectively. Illite is present in lesser quantities in all samples, with percentages ranging between 0% and 13%. Samples from the upper part of the Nkporo Shale, and the Nsukka Formation show appreciable presence of smectites and mixed layer (illite/smectites) clays. Mixed-layer clays varieties were not found in samples of the Enugu Shale and Mamu Formation. Table 1 shows the modal composition of the samples studied.

Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.8, No.11, 2018

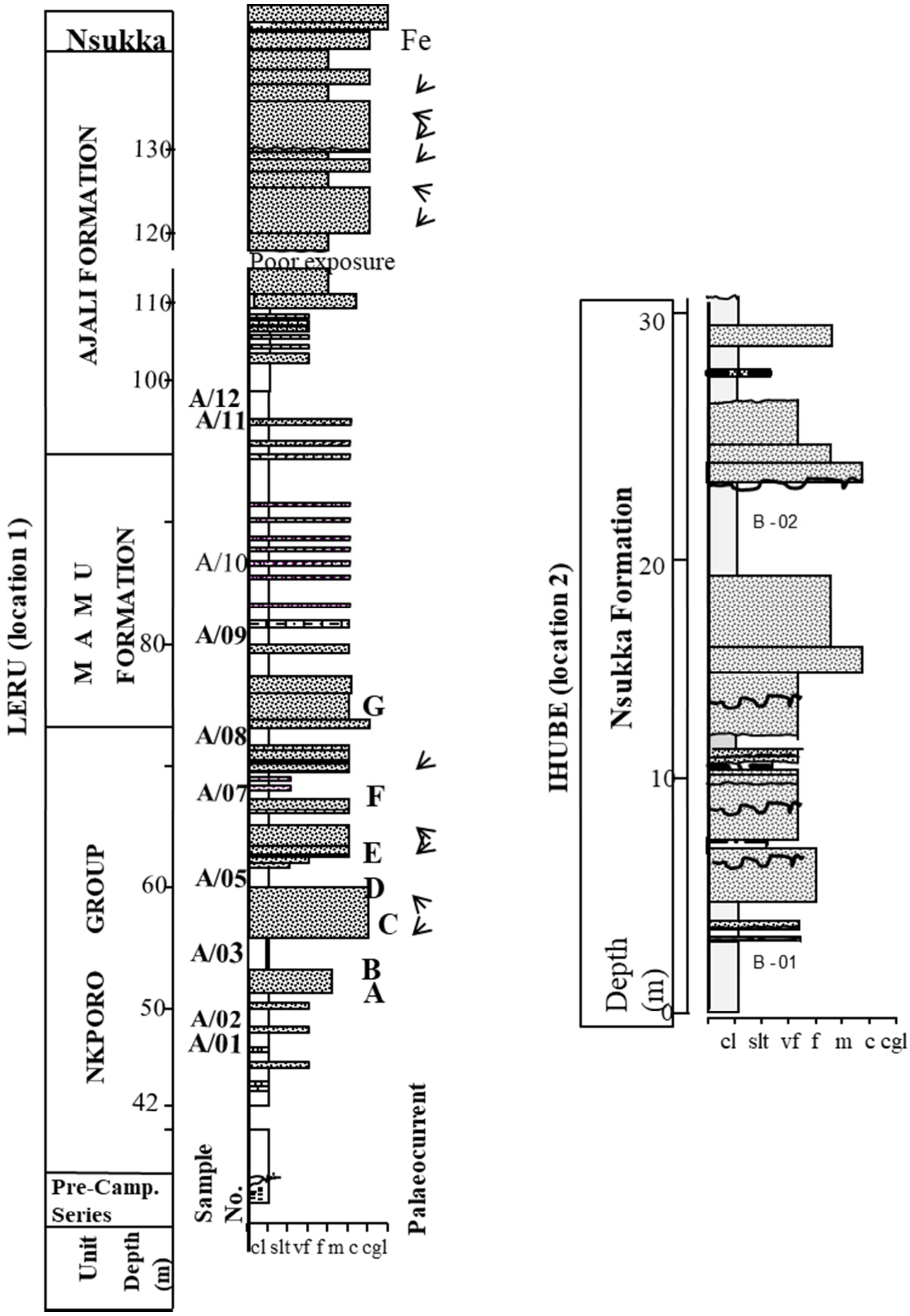

Figure 2. Sections of the Campanian-Maastrichtian succession at the Leru and Ihube outcrops showing sampled intervals (numbered A1-A8, modified after Obi and Okogbue, 2004).

Table 1. Distribution and clay mineral composition of Campanian-Maastrichtian Shales

Sample No	Formation	Quartz%	Clay %	Kaolinite %	Illite %	Smectites %	Illite/ Smectites %
B – 02 B – 01 **Average**	Nsukka	42 34 **38**	58 66 **62**	78.7 83.6 **81.2**	9.3 7.3 **8.8**	12.0 5.5 **8.7**	0 3.6 **1.8**
A – 09 A – 08 **Average**	Mamu	61 65 **63**	39 35 **37**	87.8 87 **87.4**	12.2 13.0 **12.6**	0 0 0	0 0 **0**
A – 07 A – 05 Average	Enugu Shale	58 40 **49**	42 60 **51**	90 95.5 **92.7**	10.0 4.5 **7.2**	0 0 **0**	0 0 **0**
A – 03 A – 01 **Average**	Nkporo Shale	67 58 **62.5**	33 42 **38**	66.7 81 **73.8**	12.5 9.5 **11.0**	10.4 0 **5.2**	10.4 9.5 **9.9**

Kaolinite: Kaolinite {Al_2 Si_2 O_5 $(OH)_4$} is a clay mineral characterized by a tetrahedral-octahedral layer structure of thickness 7A^o. The tetrahedral layer is near 3A^o thick, and the octahedral layer is near 4A^o.The typical basal spacing defines the 7A^o mineral (Velde, 1992; Moore 1992). Table.1 shows that there is a relative increase of kaolinite up-section. The Nkporo shale has an average kaolinite content of 73.8%; Enugu Shale has 92.7%, Mamu has 86.9%, while the Nsukka Formation has approximately 82.6%.

Illite: Illite is a dioctahedral (mica-like) mineral characterized by 2:1 interlayer ionic structure. It is distinguished from high temperature true micas by having a charge of less than 1.0 on the 2:1 unit. It is also often intimately interrelated with smectites 2:1 layers. This intimate association is called *inter layering* or *mixed layering* – it mixes different charged 2:1 units in the same crystal structure (Velde 1992). The illite is close to the muscovite structure and composition KAl_2 $(Si_3\,Al)$ O_{10} $(OH)_2$.

The site of charge imbalance for the 2:1 layer unit lies in the substitution of slightly less than one Al for an Si ion in the tetrahedrally coordinated site. Illite is thus aluminous as little charge- inducing substitution occurs in the octahedral site (Moore, 1992). The mica-like phases have similar basal spacing (near 10A^o). The percentage of the mineral illite in the samples studied is consistently low, ranging between 0% and 13%, (Table 1).

Smectite and illite/smectite: The smectites are dioctahedral-swelling clays distinguished by their Al or reciprocally their F^{3+} content. The range of charge on the dioctahedral smectite, though controversial, may extend from 0.2 to 0.6 per 2:1 unit of O_{10} $(OH)_2$ anion (Velde, 1992). The most important feature of the smectite family is the capacity to accept and exchange hydrated cations, and other polar molecules within the interlayer position.

The mineral smectites in the shale samples analyzed averages 5.2% in the Nkporo Shale, and 4.6% in the Mamu Formation, increasing to 6.1% in the Nsukka Formation (Table 1). The mixed layer (illite/ smectites) variety was not found in samples of the Enugu Shale and Mamu Formation, and averages 10.0% in the Nkporo Shale and 4.1% in the Nsukka Formation.

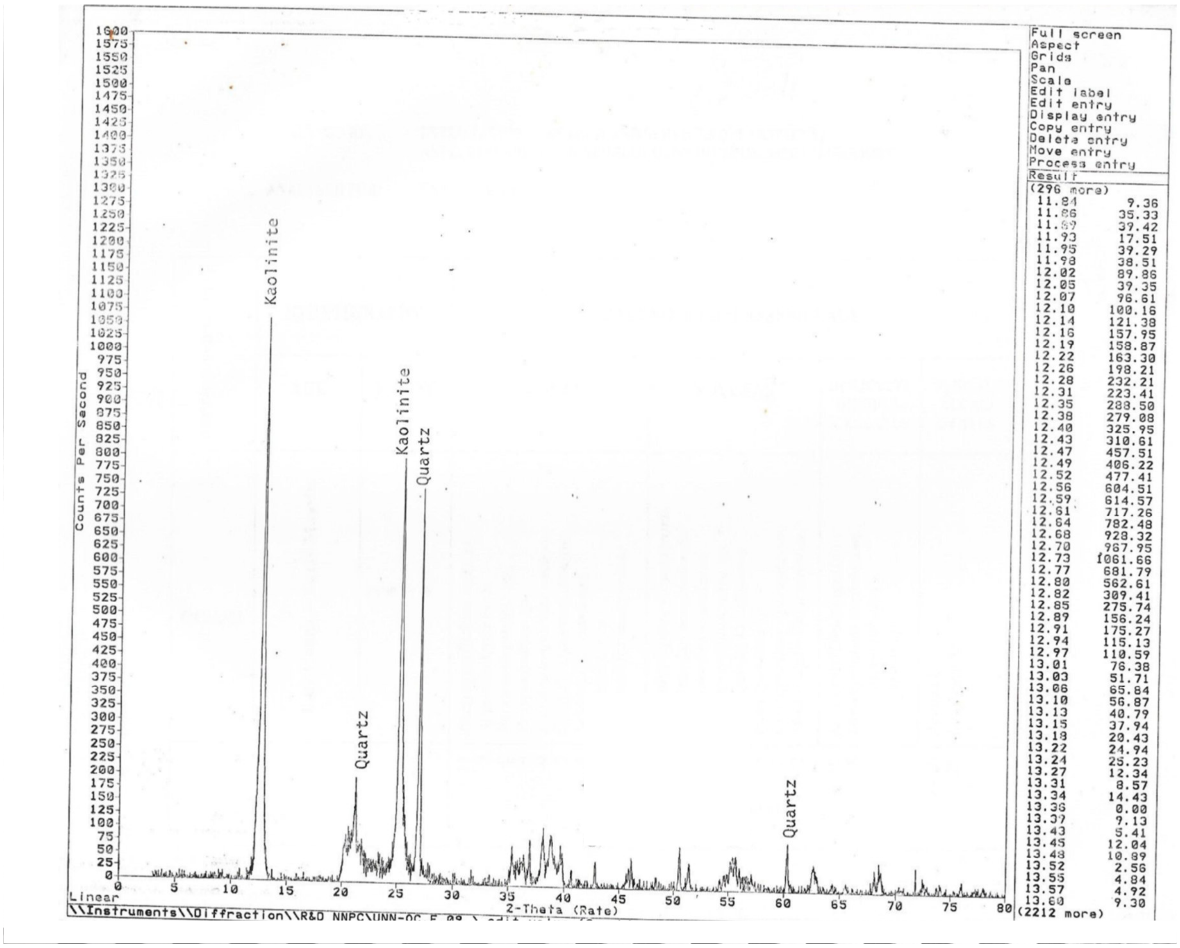

Figure 3. Typical X-ray pattern of the shales in the study areas

5. Clay Mineralogy and Provenance Implications

Clay mineral content of mud rocks is widely utilized in deciphering the likely provenance of the sediment, the conditions of deposition/palaeoclimate, and the diagenetic/burial history. These aspects of clay mineralogy have been amply reviewed by Millot (1970) and Velde (1977, 1992). Clay minerals in sedimentary rocks can originate in three ways: Inheritance (i.e detrital), neoformation (formed *in situ*), and transformation (modification of detrital clays by ion exchange or cation re-arrangement (Friedman et al., 1992). The detrital clays will provide information on the provenance of the deposit and the palaeoclimate. This is based on the fact that certain clays are specific to certain types of source rock or mineral. For example the plagioclase feldspar which is generally very unstable, gives rise to kaolinite with loss of Ca, Na, and Si in most rocks. In contrast, the generally more stable potassium feldspar produces either illite (mica) or a form of smectites, depending upon its immediate chemical environment or stage of weathering in which it is involved. Ferromagnesian minerals on the other hand, first form trioctahedral ferrous clays and then dioctahedral ferric clays (Velde, 1992).

The relative abundance of clay minerals in the shales analyzed in this work suggests primary derivation from an igneous complex dominated by intermediate to basic rocks. The Precambrian basement complex of the Cameroon, and the arkosic pre-Campanian strata of the Abakaliki Anticlinorium have been shown to be the source of the Anambra basin detritus in the study area. It is therefore assumed that the erosion of the pre-Campanian sediments and weathering of the adjoining basement blocks sourced the kaolinite-rich mud rocks of the study area. This interpretation is supported by trends in the quartz : clay mineral ratios and the kaolinite abundance in the samples analyzed.

The proportion of quartz to clay mineral in ancient fine grained epicontinental deposits is a useful indicator of the position of the shoreline. This ratio has been shown to decrease with distance from land, off major deltas, with an estimated loss of 10% quartz in every 60 km increase in distance (Griffin, 1962; Blatt and Totten, 1981). Quartz percentages in the present work decrease progressively down dip, averaging 63%, 49%, 54% and 45% in the Nkporo, Enugu, Mamu, and Nsukka Formations respectively (Table 1). Similarly kaolinite abundance maxima occur down dip. These trends are interpreted to reflect derivation from an up-dip (northerly) area, and supply into the Anambra basin by rivers.

If the above interpretation is correct, then the abundance of kaolinite suggests that the palaeoclimate was warm and humid as suggested by Hoque (1977). Keller (1964) has summarized the conditions apparently conducive to forming kaolinite at the Earth's surface. As a weathering product kaolinite implies:

(i) a high Al: Si ratio,
(ii) an acid environment, and
(iii) Na, Ca, K, Mg, and Fe absent or out of circulation.

In other words, kaolinite forms in a climate and terrain where leaching dominates, and low pH conditions prevail, the low pH commonly resulting from organic activity (Burke et al. 1971). These conditions are envisaged for the Campanian-Maastrichtian palaeoclimate in southern Nigeria. A possible explanation for the low values recorded for smectites and the mixed layer, illite/smectites, is that these minerals have been transformed diagenetically to illite, with age (Hower et al. 1976; Jennings and Thompson, 1986).

6. Conclusion

The relative abundance and distribution of clay minerals in the shales analyzed in this work suggests primary derivation from an igneous complex dominated by intermediate to basic rocks.

Trends in the quartz : clay mineral ratios and the kaolinite abundance strongly suggest derivation from the easterly Precambrian basement complex of the Cameroon, and the arkosic pre-Campanian strata of the Abakaliki Anticlinorium, and supply into the Anambra Basin by rivers. This interpretation is consistent with views held by earlier workers that erosion of the pre-Campanian sediments and weathering of the adjoining basement blocks sourced the kaolinite-rich mud rocks of the Anambra Basin. The sedimentological information provided in this paper should serve as a useful contribution to the on-going review of the sedimentology and hydrocarbon potentials of the Anambra Basin.

References

Agumanu, A. E., (1993). Sedimentology of the Owelli Sandstone (Campanian-Maastrichtian, Southern Benue trough, Nigeria. *J. M. G*., 29/2, 21-35

Allix, P., (1983). Environments mesozoiques de la partie nord-orientale due fosséde la Bénoué (Nigeria). Stratigraphie, sédimentologie, évolution géodynamique. These 3eme cycle, Travaux du Laboratoire des Sciences de la Terre, St. Jérôme, Marseille, B 21

Amajor, L. C., (1987). Paleocurrent, petrography and provenance analyses of the Ajalli Sandstone (Upper Cretaceous), southeastern Benue Trough, Nigeria. *Sediment. Geol*., 54, 47-60

Blatt, H., Middleton, G., and Murray, R., (1972). *Origin of Sedimentary Rocks*. Prentice-Hall, New Jersey, 634p

Blatt, K. H., and Totten, M. W., (1981). Detrital quartz as an indicator of distance from shore in marine mud rocks. *J. Sediment. Petrol*. 51, 1259-1266

Burke, K., (1996). The African Plate. *South African Journal Geology*, 99, 341-409

Burke, K. and Dewey, J.F., (1973). Plume-generated triple junctions: key indicators in applying plate tectonics to old rocks. *J. Geol*., 81: 406-433

Burke, K.C., Dessavagie, ET.F.G, Whiteman A.J. (1972), Geological history of the Benue valley and adjacent areas. In Dessavagie, T.F.G Whiteman A.J (eds) African Geology. University of Ibadan press Nigeria. Pp. 187-205

Burke, D. P., Jr., and Mankin, C. J, (1971). Clay mineral diagenesis with inter-laminated shales and sandstones. *J. Sediment. Petrol*., 41, 971-981.

Friedman, G.M. Sanders, J. E., and Kopaska-Merkel, D. C., (1992). *Principles of Sedimentary Deposits: Stratigraphy and Sedimentology*. Macmillan, New York, 686p

Grant, N. K., (1971). The South Atlantic, Benue Trough and Gulf of Guinea Cretaceous triple junction. *Geol. Soc. America Bull*., v. 82, p. 2295-2298

Griffin, G. M., (1962). Regional clay-mineral facies - product of weathering intensity and current distribution in the northeastern Gulf of Mexico. *U.S.A. Bull*., 73,737-768

Hoque, M., (1977). Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. *Sediment. Geol*., 17, 235-245

Hoque, M., and Ezepue, M. C., (1977). Petrology and Palaeogeography of the Ajali Sandstone. *J. Min. Geol*. 14, p. 16-22

Hower, J., Eslinger, E. V., Hower, M. E., and Perry, E. A. (1976). Mechanism of burial metamorphism of argillaceous sediment. *Bull. Geol. Soc. Am*., 87, 725-737

Jennings, S. and Thompson, G. R., (1986). Diagenesis of Plio-Pleistocene sediments of the Colorado River delta, Southern California. *J. Sediment. Petrol*., 56, 89- 98

Keller, W. D., (1964). Processes of origin and alteration of clay minerals. In: soil and clay mineralogy. Univ. of N. Car. Press. Chapel Hill

Moore, D. G., and Scruton, P. C., (1957). Minor internal structures of some recent unconsolidated sediment.

AAPG. Bull. 41. 2723-2751

Moore, S. E., Ferrell, R. E. Jr., and Aharon, P., (1992). Diagenetic siderite and other ferroan carbonates in a modern subsiding marsh sequence. *J. Sediment. Petrol*., 62 / 3, 357-366

Nwachukwu, S. O., (1972). The tectonic evolution of the southern portion of the Benue Trough, Nigeria. *Geol. Mag*. 109, 411-419

Obi G.C. (2000). Depositional model for the Campanian-Maastrichtian Anambra Basin, Southern Nigeria. Ph.D. Thesis, University of Nigeria, Nsukka, Nigeria.

Obi, G.C and Okogbue, C. O., (2004). Sedimentary response to tectonism in the Campanian-Maastrichtian succession, Anambra Basin, South-eastern Nigeria. *Journal African Earth Sciences*, 38, 99-108

Ojoh, K. A., (1992). The southern part of the Benue Trough, (Nigeria); Cretaceous stratigraphy, basin analysis, palaeoceanography and geodynamic evolution in the equatorial domain of the south Atlantic. *NAPE Bull*. 7 / 2, 131-152.

Olade, M. A., (1975). Evolution of Nigeria's Benue Trough (Aulacogen): a tectonic model: *Geol. Mag*., v. 112, p. 575-583.

Petters, J. W. (1978). Stratigraphic evolution of the Benue trough and its implications for the Upper Cretaceous palaeogeography of West Africa. *J. Geol*., 86, 311-322

Velde, B., (1977). *Clays and clay minerals in natural and synthetic systems*. Elsevier, Amsterdam.

Velde, B., (1992). *Introduction to clay minerals*. Chapman and Hall, 198p