

## Sequence Stratigraphy Of Amansiodo-1 Well, Anambra Basin, South-East, Nigeria

<sup>1</sup>M. T. Kovona, <sup>2</sup>I. Hamidu, E.C. <sup>3</sup>Nwaejije, E.O. <sup>4</sup>Obiosio, T. Najime  
Department of Geology, Ahmadu Bello University, Zaria Nigeria

### ABSTRACT

A sequence stratigraphic analysis was carried out on ditch cutting samples from Amansiodo-1 well, Anambra Basin Nigeria. The analysis based on foraminiferal species (population and diversity) obtained from the ditch cuttings revealed two systems tract (transgressive systems tract and lowstand systems tract); a maximum flooding surface (proposed at 682 m) and a sequence boundary (proposed at 1667 m) establishing an incomplete depositional sequence for the well. The mid-section of the transgressive systems tract (1267-1122 m) shows sand and shale intercalation which is characteristic of a good reservoir rock.

**Keywords:** Anambra Basin, Maximum Flooding Surface, Sequence Boundary.

### INTRODUCTION

Sequence stratigraphic approach involves the study of rock relationship within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion and non-deposition of their correlative conformities (Van Wagoner et al., 1988). This concept is based on the response of sediments to change in base level and the depositional trends that emerge from the interplay of accommodation space available for sediments to fill and the sedimentation (Catuneanu, 2006). This concept has been used successfully to understand oil and gas plays.

The framework of sequence stratigraphy is time and this is amplified by biostratigraphy as it provides information for the organization of sequence boundaries and maximum flooding surfaces (Emery and Myers, 1996; Nwaejije et al., 2017). The strong link between organisms and change in relative sea level provides biostratigraphic data used to recognize key strata surfaces, systems tract and The Anambra Basin is a structural (synclinal) depression and one of the intracratonic basins, whose sedimentary succession directly overlies the sedimentary rocks of the Southern Benue Trough, and consists of Campanian to Paleocene lithofacies. The basin lies between latitude 05° 00' 00" to 08° 00' 00" N and longitude 06° 18' 00" to 08° 00' 00" E with an approximate area of 40,000 km<sup>2</sup> (Nwajide and Reijers, 1996). It is bounded to the west by the Okitipupa Ridge; to the northwest, it overlies the basement complex between Auchi and Igarra in Edo State; the northern boundary is with the basement complex of Keffi - Wamba area while the Niger Delta marks the southern limit (Fig 1).

In territorial terms, the outcropping area of the basin has a roughly triangular outline (Nwajide, 2013). The basin is characterized by enormous lithologic heterogeneity in both vertical and lateral extension derived from a range of paleoenvironmental settings ranging from Campanian to Recent (Akaegbobi, 2005).

parasequences (Emery and Myers, 1996). The ability to define sequence boundaries and systems tracts using biostratigraphic data is limited by the resolution of the marker available, but where such are absent/insufficient, Armentrout and Clement (1990) proposed that minimal faunal abundances have the potential to be used to recognize periods of maximum regression which is useful in delineating sequence boundaries.

The objective of this study is to contribute to the stratigraphic investigation of the Anambra basin and hence advance our understanding of the basin. In this study, systems tract and depositional sequence interpretation are integrated with results of foraminiferal species and lithostratigraphic interpretation of Amansiodo-1 well to establish a sequence stratigraphic framework for the well.

### Geology of Anambra Basin

Sedimentation in the Anambra Basin commenced with the deposition of the Campanian-Maastrichtian marine and paralic shales of the Nkporo and Enugu formations which are overlain by Coal Measures (Mamu, Ajali and Nsukka formations) which is in turn overlain by the Paleocene Imo Formation and Eocene Ameki Formation (Fig 2). The Nkporo Formation consists primarily of dark grey fissile shales and mudstone, often pyritic or gypsum-bearing (Zaborski, 1998). The Nsukka Formation overlies the Ajali Formation and consists of sandstones, shales with bands of limestone (Reyment, 1965; Obi et al., 2001). The Imo Formation consists of blue-grey clays and shales with bands of calcareous sandstones, marls and limestone (Reyment, 1965). The Ameki Formation is predominantly alternating shales, sandy shales, clayey sandstone and fine-grained fossiliferous sandstone with thin limestone bands (Reyment, 1965; Arua, 1986).

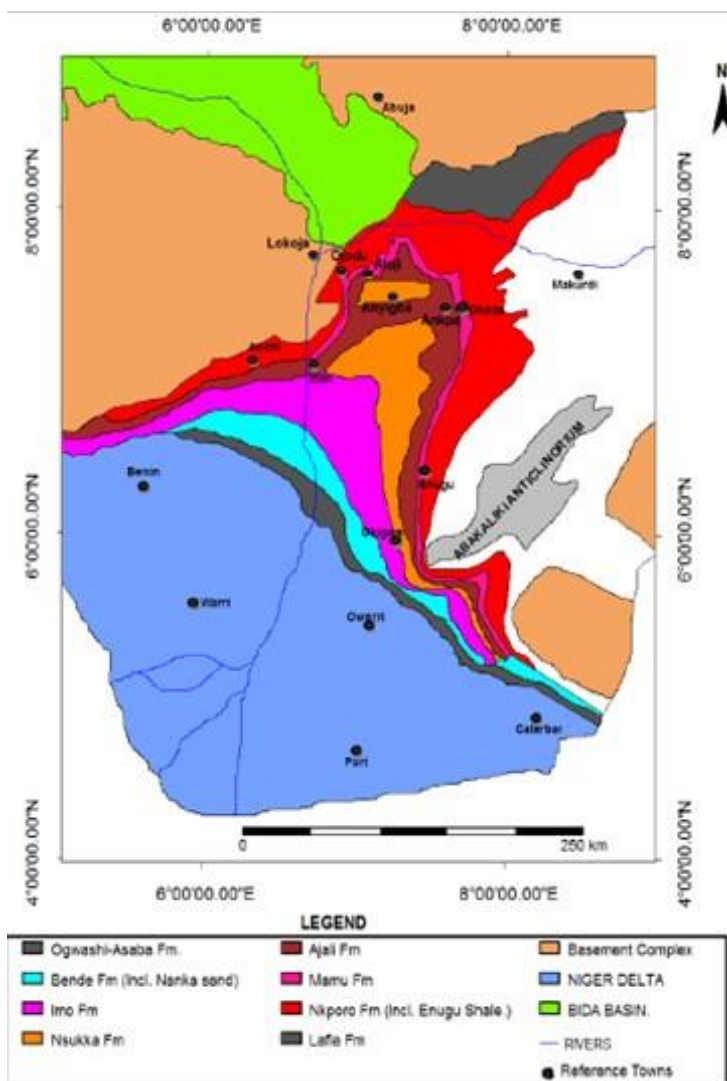


Figure 1: Geological sketch map of the Anambra Basin (After Obaje, 2009).

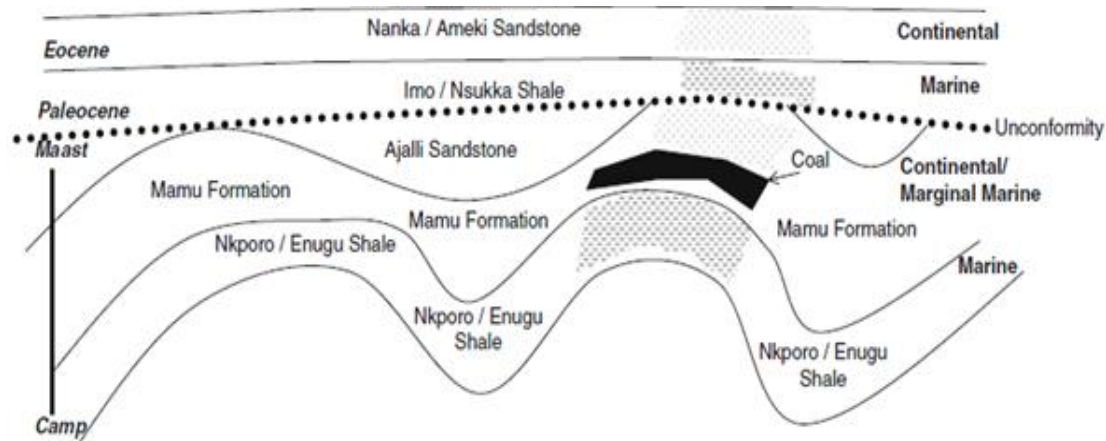


Figure 2: Stratigraphic succession of the Anambra Basin (after Obaje 2009)

## METHODOLOGY

The approach employed in the stratigraphic analysis of the well is based on the study of the foraminiferal components of the sediments and lithological facies to interpret the sequence boundaries. Foraminiferal species were recovered from sixty-two ditch cutting samples obtained from Amansiodo-I well, Anambra Basin. The samples were composited at 18 m interval with a total thickness of 1771 m; the procedure adopted for microfossil extraction is the standard micropaleontological sample preparation technique (Pessagno, 1967; Zingula, 1968; Brasier, 1980). The foraminiferal species recovered were picked with the aid of a water based gum and mounted into a micropaleontological slide cavity and covered with a slip. These slides were arranged serially for identification by comparing with forms previously described by Sellier de Crivrieux (1976), Petters (1979a, 1979b, and 1982), Bolli et al. (1994), Jones (1994) and Gebhardt (1997, 1998). Scanning electron micrographs (SEM) of recovered foraminifera are taken. The good data were analysed using the stratabug software. Interpretation of the biostratigraphy and paleoenvironment of the penetrated stratigraphic section is the first step in the sequence stratigraphic analysis (Wornardt and Vail, 1991; Armentrout, 1991; Mitchum and Van Wagoner, 1991). This is aimed at establishing the chronostratigraphic frameworks within which sediment packages are subdivided and characterized. The maximum flooding surfaces are

interpreted from foraminiferal abundance and diversity. Similarly, a possible sequence boundary was interpreted using low foraminiferal abundance and diversity.

## RESULTS

### Foraminifera

The foraminifera recovered is well preserved and their diversity is high. The forms recovered were the benthonic (arenaceous and calcareous) foraminifera with most having long stratigraphic ranges while others had restricted distribution.

#### Benthonic Foraminifera

The benthonic foraminiferal species in the well are made up of rich to occasionally abundant species with fairly good preservation through the section. A total of thirty species were identified from the study interval; four of which are calcareous benthonic species and twenty-six arenaceous species (Table 1). The benthonic foraminifera are dominated by species of *Haplophragmoides sahariense*, *Haplophragmoides sahariense*, *Haplophragmoides sahariense* sp., *Ammobaculites amabensis*, and *Ammobaculites* sp. (with a foraminifera count of above 20). Some others have poor representation with a single occurrence, in the case of *Ammotium* cf *nkalangum*, *Miliammina tsogaensis*, *Marginulina dorsata*, *Lenticulina* sp. and *Marginulina* sp.

**Table 1:** Benthonic foraminifera total count

Arenaceous Assemblages (FOBA)	Total Count Per 30 g	Calcareous Assemblage (FOBA)	Total Count
<i>Haplophragmoides sahariense</i>	93	<i>Marginulina dorsata</i>	1
<i>Ammobaculites amabensis</i>	34	<i>Gavelinella sahariense</i>	4
<i>Ammobaculites jessensis</i>	4	<i>Lenticulina</i> sp.	1
<i>Haplophragmoides sahariense</i>	26	<i>Marginulina</i> sp.	1
<i>Haplophragmoides talokaense</i>	12		
<i>Ammobaculites numanhensis</i>	3		
<i>Ammobaculites</i> sp.	22		
<i>Ammotium</i> sp.	5		
<i>Haplophragmoides</i> sp.	24		
<i>Miliammina onyeamensis</i>	2		
<i>Miliammina pindigensis</i>	4		
<i>Textulariopsis dukamajina</i>	3		
<i>Trochammina afikpensis</i>	2		
<i>Trochammina dutsuna</i>	6		
<i>Trochammina</i> sp.	7		
<i>Arenaceous indet</i> sp.	9		
<i>Ammobaculites pindigensis</i>	2		
<i>Ammotium</i> cf <i>bornum</i>	1		
<i>Haplophragmoides hausa</i>	3		
<i>Ammobaculites bauchensis</i>	2		
<i>Ammotium</i> cf <i>nkalangum</i>	5		
<i>Miliammina tsogaensis</i>	1		
<i>Ammotium nkalangum</i>	6		
<i>Saccammina</i> sp.	1		
<i>Miliammina</i> sp.	3		
<i>Reophax</i> sp.	2		
<b>Total count</b>	<b>282</b>		<b>7</b>

### Sequence Stratigraphic Units

Sequence stratigraphic analysis of the well is based on lithostratigraphic data and foraminiferal species recovered from the well. From the analysis, two systems tract as well as associated key surfaces were delineated and include transgressive systems tract (TST), lowstand systems tract (LST), maximum flooding surfaces (MFS) and sequence boundaries (SB).

#### Associated Key Surfaces

The maximum flooding surfaces (MFS) and sequence boundaries (SB) derived from foraminiferal peaks, abundance and diversities are identified basically on the inflection from overall progradation to overall retrogradation of parasequences.

**Maximum Flooding Surface (MFS) at 682 m:** Biostratigraphic analysis of the sediments in the Amansido-1 well shows the highest abundance and diversity of microfauna at 682 m. The lithostratigraphic analysis shows grey to brown mudstone with coal intercalation. Both analyses show the interval to be characteristic of the maximum flooding surface (MFS). Other minor flooding surfaces marked by an abrupt increase in foraminifera diversity include 829 m, 994 m, 1070 m.

**Sequence Boundary at 1667 m:** Biostratigraphic analysis of the sediment encountered in Amansido-1 well shows a

decrease in foraminiferal abundance and diversity at 1667 m. It is characterized by non-deposition of fossils typical of a sequence boundary (Fig. 3).

#### Systems Tracts of sediments in Amansido-1 well

**Transgressive Systems Tract (TST):** Biostratigraphic analysis of the sediments shows remarkable increase in foraminiferal assemblages and diversity, marked at the top by Maximum Flooding Surface (682 m) which indicate an influx of foraminiferal species counts (4-13) and a sequence boundary (1667 m) as the base which shows a paucity of microfauna. The lithostratigraphic analysis shows the interval to be predominantly shale at the base; the mid-section is sand and shale intercalation while mudstone with coal intercalations caps the top of the interval (Fig 3). The sand-shale ratio indicates an increase of sand towards the top of the interval. The analyses show the interval to be typically a transgressive systems tract (TST).

**Lowstand Systems Tract (LST):** Biostratigraphic analysis shows a remarkable decrease in foraminiferal abundance from four to zero (barren), indicating a shallowing from shallow inner neritic to the non-marine environment. The lithostratigraphic analysis shows the interval to be characterized by shale lithofacies. The interval is typical of a lowstand systems tract (LST). The interval is marked at the top by the sequence boundary (SB, Fig. 3)

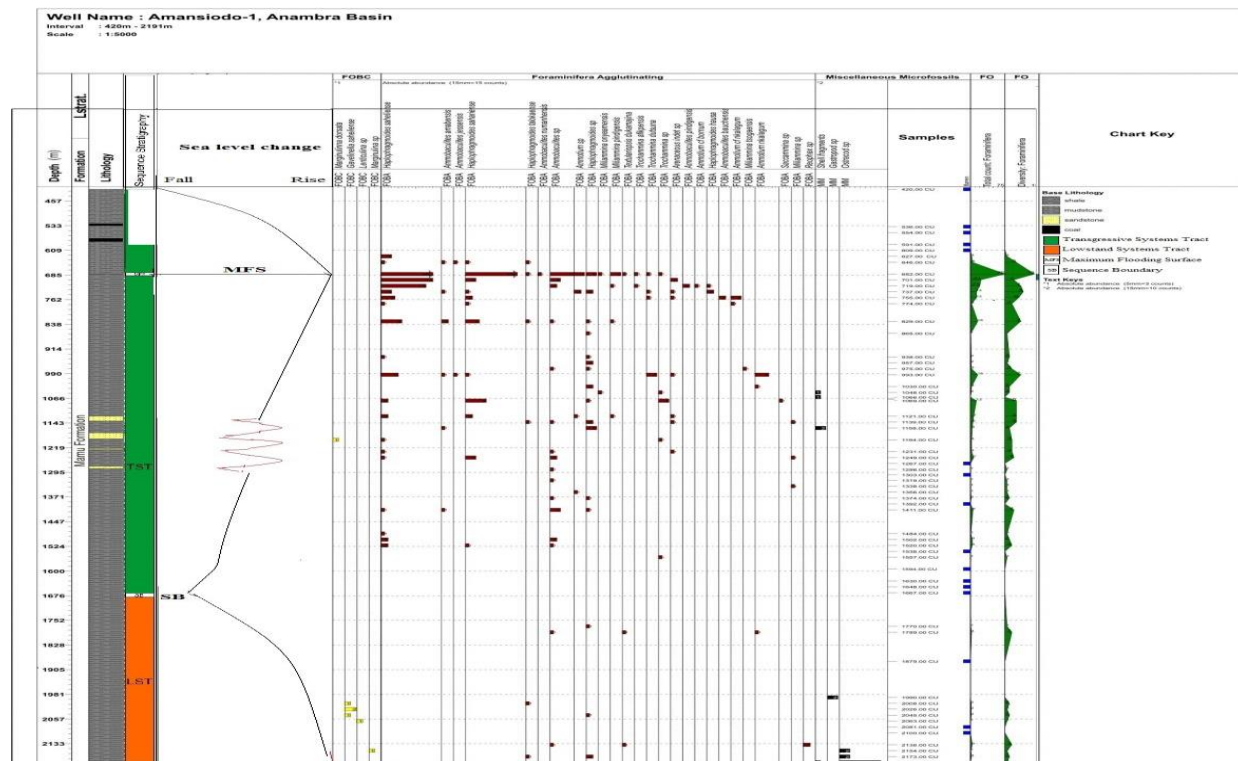


Figure 3: Sequence stratigraphic section of Mamu Formation, Amansido-1 well

## DISCUSSION

### Sequence Stratigraphy

Sequence stratigraphic analysis of the sediments in the well was based on foraminiferal biostratigraphic chart generated for the formation in the well. The sequence stratigraphic analysis employed similar approaches by Armentrout (1987), Armentrout and Clement (1990), Pacht et al. (1990), and Vail and Wornardt (1990), Armentrout et al. (1990), Armentrout (1996), Armentrout et al. (1999), Catuneanu (2002, 2006) and Boggs (1995).

Sequence stratigraphic analysis of the studied sediments encountered in Amansiodo-1 well based on foraminiferal and lithostratigraphic data revealed two systems tract (transgressive systems tract and lowstand systems tract), a maximum flooding surface (MFS) proposed at 682 m, and a sequence boundary (SB) proposed at 1667 m. The mid-section of the transgressive systems tract shows sand and shale intercalation which is characteristic of a good reservoir rock. (1267-1122 m).

The abundance of benthonic foraminifera in the various systems tract shows the sediments to have been deposited in a marine environment while the interval above the Maximum Flooding Surface (682 m) depicts a decrease to total absence of microfauna (foraminifera) which shows a shift from marine to probably fluvial environment, as such the coals as seen in the lithostratigraphic section could represent a floodplain deposit.

### Depositional Sequence

Generally, a depositional sequence consists of lowstand systems tract (LST), transgressive systems tract (TST), falling stage systems tract (FSST) and highstand systems tract (HST). It is a stratigraphic unit composed of a relatively conformable succession of genetically related strata bounded at the top and base by unconformities or their correlative conformities, known as sequence boundaries (Reijers, 1996). On this premise, an incomplete depositional sequence was recognized in the penetrated interval of Amansiodo-1 well.

## CONCLUSIONS

This study developed a sequence stratigraphic framework for the Mamu Formation in the Anambra Basin using foraminiferal species analysis from Amansiodo-1 well, revealing two (2) systems tract (transgressive and lowstand), a maximum flooding surface (proposed at 682 m) and a sequence boundary (proposed at 1667 m) establishing an incomplete depositional sequence from the sediments in the studied well.

## ACKNOWLEDGEMENT

The authors wish to acknowledge Mr Luke Abu (deputy director NGS Kaduna) for allowing access to the ditch cutting samples used for this study.

## REFERENCES

Akaegbobi, I.M. (2005). Sequence stratigraphy and predictive hydrocarbon source potential of the Campano-Maastrichtian shale outcropping at Enugu, Anambra Basin, Nigeria. *Nigerian*

*Association of Petroleum Explorationist, 23<sup>rd</sup> Annual International conference book abstract. A40*

- Armentrout, J.M. (1996). High resolution sequence biostratigraphy: an example from the Gulf of Mexico, Plio-Pleistocene. In: Howel, J.A., Aitken, J.F. (Eds.), *High Resolution Sequence Stratigraphy: Innovations and Applications*. Geological Society Special Publication. 65 - 86.
- Armentrout, J.M., Clement, J.F. (1990). Biostratigraphic correlation of depositional cycles: a case study in High Island-Galveston-East break areas, offshore Texas. In: Gulf coast section, Society of economic paleontologist and mineralogists. In: Eleventh Annual Research Conference, Huston. 21 - 51.
- Armentrout, J.M. (1987). Integration of biostratigraphy and seismic stratigraphy: pliocene- pleistocene, Gulf of Mexico. In: Gulf coast section, the society of economic palaeontologist and mineralogists. In: Eighth Annual Research Conference. 1 - 6.
- Armentrout, J.M., Echols, R.H., and Lee, T.D. (1990). Patterns of foraminiferal abundance and diversity: implications of sequence stratigraphic analysis. In: Armentrout, J.M., Perkins, B.F. (Eds.), *Sequence Stratigraphy as an Exploration Tool: Concepts and Practices in the Gulf Coast*. Gulf Coast Section SEMP Foundation Eleventh Annual Research Conference Program and Abstracts. 53 - 58.
- Armentrout, J.M. (1991). Patterns of foraminiferal abundance and diversity: implication for sequence stratigraphic analysis. *American Association of Petroleum Geologist Bulletin*.75: 535.
- Armentrout, J.M., Feam, B., Rodgers, K., Root, S., Lyle, W.D., Hedrick, D.C., Bloch, R.B., Snedden, J.W., Nwankwo, B. (1999). High resolution sequence biostratigraphy of a lowstand prograding deltaic wedge: oso field (Late Miocene), Nigeria. In: Jones, R.W., Simmons, M.D. (Eds.), *Biostratigraphy in Production and Development Geology*, Geological society, London, Special Bulletin. 152: 259 - 290.
- Arua, I. (1986). Paleoenvironment of Eocene deposits in the Afikpo syncline, southern Nigeria. *Journal of African Earth Sciences* 5: 279 – 284.
- Boggs, S (1995). Principles of sedimentology and stratigraphy. *Prentice Hall, Englewood Cliffs, New Jersey*. 79 - 93
- Bolli, H.M., Beckmann, J.P. and Saunders, J.B. (1994). *Benthic Foraminiferal Biostratigraphy* 412 of the *South Caribbean Region*: Cambridge, U.K., Cambridge University Press. 408.
- Brasier, M.D. (1980). *Microfossils*. Univ. Hull Press, Kingston-upon-Hull, UK. 193.
- Catuneanu, O. (2002). Sequence stratigraphy of clastic systems: concepts, merits, and pitfalls. *Journal of African Earth Sciences*. 35(1): 1 - 43.
- Catuneanu O. (2006) *Principles of Sequence Stratigraphy*. Elsevier, Linacre House, Jordan Hill, Oxford, OX2, 8DP, United Kingdom. 171 - 219.
- Emery, D., and Myers, K.J. (1996). *Sequence Stratigraphy*. Blackwell, Oxford, UK. 297.

- Gebhardt H. (1997). Cenomanian to Turonian foraminifera from Ashaka (NE Nigeria): quantitative analysis and palaeoenvironmental interpretation. *Journal of Cretaceous Research* v. 18: 17 - 36
- Gebhardt H. (1998). Benthic Foraminifera from the Maastrichtian lower Mamu Formation near Leru (southeast Nigeria) *Journal of Foraminiferal Research* 28: 76 - 89
- Jones, R.W. (1994). Biostratigraphy in Production and Development Geology, Geological society, London, Special Bulletin. 152: 259 - 290.
- Mitchum Jr., R.M., and Van Wagoner, J.C. (1991). High-frequency sequences and their stacking patterns: sequence stratigraphic evidence of high-frequency eustatic cycles. *Sedimentary Geology* 70: 131 - 160.
- Nwaejije, E.C. Hamidu, I. and Obiosio, E.O. (2017). Early to middle Miocene sequencestratigraphy of well-5 (OML 34), Niger Delta, Nigeria. *Journal of African Earth Sciences*. 129: 519 - 526
- Nwajide, C.S. (2013). *Geology of Nigeria's Sedimentary Basin*, CSS Bookshops Limited, Lagos, 277 - 346.
- Nwajide, C.S and Reijers, T.J.A. (1996a). Geology of the Southern Anambra Basin. In: Reijers, T.J.A. (Ed.), Selected Chapters on Geology. Shell Petroleum Development Company, Warri. 133 – 148.
- Nwajide, C.S. and Reijers, T.J.A. (1996b). Sequence architecture in outcrops: examples from the Anambra Basin. *Nigerian Association of Petroleum Explorationist Bulletin*. 11: 23 - 32
- Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. *Lecture notes in Earth Science, Springer-Verlag Berlin Heidelberg*. 58 - 62.
- Obi, G.C., Okogbue, C.O., and Nwajide, C.S. (2001). Evolution of the Enugu Cuesta: A tectonically driven erosional process. *Global Journal of Pure and Applied Sciences*, 7(2): 321 - 330.
- Pacht, J.A., Bowen, B.E., Beard, J.H., and Shaffer, B.L. (1990). Sequence stratigraphy of Plio- Peistocene depositional facies in the offshore Louisiana south addition. *Gulf Coast Association Geology Society* 40: 1 - 18.
- Pessagno Jr., E.A. (1967). Upper Cretaceous stratigraphy of the western Gulf coastal plain. *Palaeontology. Americana*. 5(37): 245 - 445.
- Petters S.W. (1979a). Maastrichtian arenaceous foraminifera from northwestern Nigeria: *Palaeontology*. 22: 947 - 963.
- Petters S.W. (1979b). Paralic arenaceous foraminifera from the Upper Cretaceous of the Benue Trough, Nigeria. *Acta Palaeontologica Polonica*, 24: 451 - 471
- Petters, S.W. (1982). Central West African cretaceous-tertiary benthic foraminifera and stratigraphy. *Palaeontogr*. 179: 104.
- Reijers, T.J.A. (1996). Selected Chapters in Geology: Sedimentary Geology and Sequence Stratigraphy in Nigeria and Three Case Studies and Field Guide. Shell Petroleum Development Company, Nigeria. 197.
- Reyment R.A. (1965). *Aspects of the geology of Nigeria*. University Press in Ibadan, Nigeria. 143
- Sellier de Crivrieux, J.M., (1976). Estudio sistemático y ecológico de las Bolivinitidae recientes de Venezuela. *Cuad. Oceanography*. 5: 3 - 43.
- Vail, E.R., and Wornardt, W.W. (1990). Well-log seismic stratigraphy: an integrated tool for the 1990s. In: Sequence Stratigraphy as an Exploration Tool: Concepts and Practices in the Gulf coast. Gulf coast section of the Society of Economic Paleontologists and Mineralogists, eleventh annual research conference. 379 - 397.
- Van Wagoner, J.C., Posamentier, H.W., Mitchum, R.M.Jr., Vail, P.R., Sarg, J.F., Loutit, T.S. and Hardenbol, J. (1988). An Overview of Sequence Stratigraphy and Definitions, Sea level changes, an integrated approach, in C. K. Wilgus, B. S. Hastings, H.M. Posamentier, J.C. Van Wagoner, C.A. Ross, and C. G. Kendall, (eds.) *Society of Economic Paleontologist and Mineralogist special publications*, 42: 39 - 45
- Whiteman, A.J. (1982). Nigeria, its Petroleum Geology, Resources and Potential I and II. Graham and Trotman, Edinburgh.
- Wornardt, and W.W., Vail, P.P.R. (1991). Revision of the plio-pleistocene cycles and their application to sequence stratigraphy and shelf and slope sediments in the Gulf of Mexico. *Gulf Coast Assoc. Geol. Soc. Trans*. 41: 719 - 744.
- Zaborski, P.M. (1998). A review of the Cretaceous Systems in Nigeria. *Africa Geoscience Review* 5: 26 - 30
- Zingula, R.P. (1968). A new breakthrough in sample washing. *Journal of Paleontology* 42(4): 1092.