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ENVIRONMENT OF DEPOSITION OF THE AWGU FORMATION (LATE CRETACEOUS), SOUTHERN BENUE TROUGH, NIGERIA

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ABSTRACT

The Awgu Formation is a linear NE-SW trending sedimentary deposit composed of the Ogugu Shale at the base and overlain by the Agbani Sandstone. There are carbonate-shale and sandstone facies representing a coarsening-upward (CU) succession from a muddy shelf to an upward-building sandy shoal.

The blue gray shale with some pyrite indicates a marine environment that occasionally attained anoxic levels. The carbonates are wackestone-packstone of facies zone (FZ) 7 of Wilson (1975), indicative of platform carbonates with open circulation and tropical conditions. Clay mineral suites rich in smectite/ illite and smectite, and the glauconite present in the fine arenaceous facies, suggest a shallow marine depositional environment not exceeding 50 m water depth.

The formation was folded and faulted in places with the folds arranged *en echelon* parallel to the NE – SW trending axis of the Benue Trough while the fractures are perpendicular to the said basin's axis. The formation is a remnant of the original deposits having been eroded subsequent to the Late Santonian deformation, uplift and erosion of the Benue depression.

The sandstone geometry (Length = 10 km, width = 10 km and exposed thickness = 45 m) together with the upward increase in the number, thickness and angle of dip of cross-beds, typifies shallow marine sandstones. The bipolar-bimodal model of paleocurrrent directions as well as high variance are attributable to tidal currents and occasional oscillatory waves during the deposition of the Awgu Formation.

KEY WORDS: Southern Benue Trough, Awgu Formation, muddy shelf, sandy shoal, Santonian, marine, tidal.

INTRODUCTION

The Southern Benue Trough (SBT) is the southwestern part of a NE-SW trending intracratonic sedimentary domain (aulacogen) which extends from under the Niger Delta Basin and continues below the Chad Basin beyond into the Chad and Niger Republics (Benkhelil *et al*., 1989).

The N 60° E-trending Abakaliki Anticlinorium, the Afikpo Syncline and the Anambra Basin are the prominent structural features in the area. The Benue Trough facies were deposited nonconformably on the crystalline Basement Complex in this part of the trough and lie within longitudes 7° 30' and 8° 0'E and latitudes 6° 0' and 6° 30' N. A part of this area was studied as indicated in Figure 1. Geologic units ranging from the Asu River Group (Middle-Late Albian) at the base to the Enugu Formation (Campanian-Maastrichtian) at the top were deposited here by transgressive-regressive movements of the sea during the Cretaceous (Murat, 1972; Petters, 1980).

The Awgu Formation constitutes one of the pre-Santonian units in the area (Hoque, 1977). It occupies a narrow strip between the eastern flank of the cuesta between Enugu and Awgu and the gently rolling land north of Ndeaboh. The formation strikes NE-SW with dips between 5° and 20°. Dessauvagie (1974) estimated a maximum thickness of 900 m for the formation while oil well data indicated a thickness of between 600 m and 750 m (Avbovbo and Ogbe, 1978). The formation is probably thicker than has been recorded. As one of the sedimentary units of the third depositional cycle (Late Turonian- Early Santonian) in the Benue Trough, it has been largely removed by erosion following the Late Santonian deformation and uplift of the Benue depression (Murat, 1972). The formation is now a remnant of sediments belonging to that cycle (Olade, 1975). Petters (1978) found it practically impossible to distinguish between the "EzeAku" and Awgu Formations in the field, while Reyment and Offodile (1976) could not separate the two sedimentary units. The present study shows that the formation is

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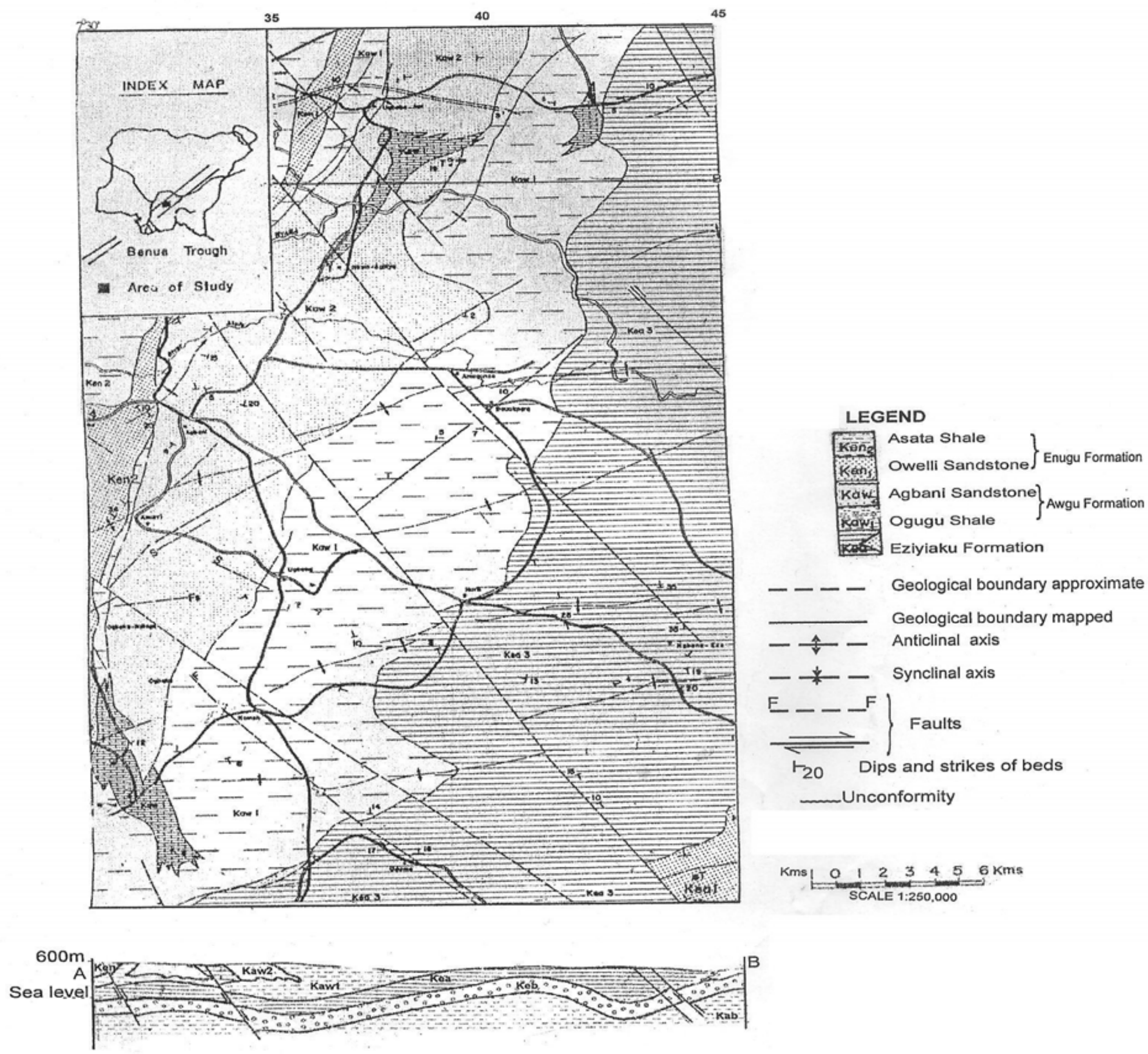

Figure 1: Geological map of part of the Southern Benue Trough showing the Awgu Formation and other lithologic units.

delineated from the subjacent Eziyiaku Formation by carbonate (hiatus) concretions suggestive of geologic discontinuity (Kennedy *et al*., 1977; Baird 1978). Such concretions were observed at Nkpana Ukwu (7° 43' E and 6° 11' N). The formation is distinguished from the underlying Eziyiaku Formation by its grayish, shelly limestone pavements along the stream at Ogugu. Each limestone pavement is about 10-30 cm thick and consists of crowded oyster shells cemented by calcareous materials. The unit coarsens upward from carbonate-shale base to coarse-grained sandstone at the top. Fossils, including ammonites and foraminifers, indicate a Late Turonian-Santonian age for the deposit(Reyment, 1965, p 47, table VII- 4; Petters, 1980).

LITHOSTRATIGRAPHIC UNITS

The Awgu Formation is one of the sedimentary formations in the Southern Benue Trough which is located east of the Anambra Basin (Benkhelil et al 1989, fig. 2). Its stratigraphic relationship to the other sedimentary units in the Southern Benue Trough is shown in Figure 2. The formation consists mainly of shale, shelly limestone, siltstone and sandstone. Two members are distinguished on the basis of their lithology, namely, the Agbani Sandstone Member at the top underlain by the Ogugu Shale Member.

The Ogugu Shale Member

This member is described at the designated type section (lectostratotype) along the River Okpa Agbo at Ogugu village, southeastern Nigeria. It is bluish-gray at the top.

The bottom is sandy, bluish-gray black and occasionally pyritic with siltstone intercalations, probably Petters and Ekweozor's (1982) sub-tidal sandstone intercalations. The top grades into the overlying Agbani Sandstones in places. Grayish, shelly limestones form alternate pavements with shale along the stream at Ogugu. Cemented and pyritised shells also constitute the limestone bands at Nenwe and Mgbowo; some ammonites and a rich accumulation of pelecypod

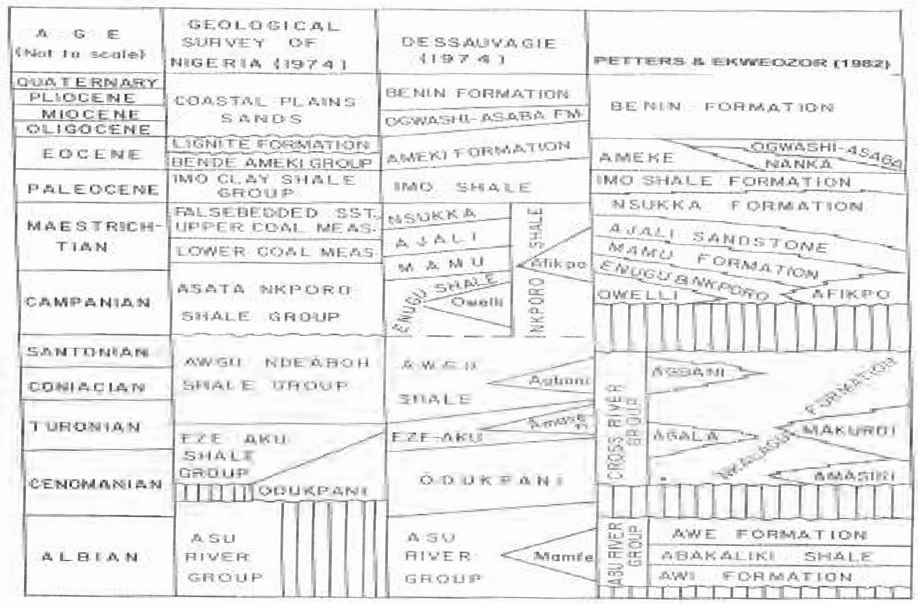

Fig. 2 Stratigraphic subdivision of Benue Trough and the location of the Awgu Formation.
ADAPTED FROM PETTERS AND EKWEOZOR (1982, fig 2)

Figure 2: Stratigraphic subdivision of Southern Benue Trough and the location of the Awgu Formation. Adapted from Petters and Ekweozor (

valves (*Exogyra*) also occur. The limestone-shale terrain often weathers into fawn or pale yellow clay. A band of gypsiferous remains, about 3 cm thick, occurs locally in the shale outcrop around Awgu.

The Agbani Sandstone Member

The Agbani Sandstone was described as a time equivalent of the Ogugu Shale by Reyment (1965, p. 49). The unit is probably the "pale yellow calcareous sandstone of the Awgu Formation" studied by Simpson (1954, p.10) and described by Hoque (1977) as a pre-Santonian, weathered, feldspar-rich sandstone. It is a NE-SW trending lensoid sandstone body which is difficult to trace and map laterally due to poor exposures. It is estimated to be 40 km long and 10 km wide with an exposed thickness of 30-50 m. It is thickest at the type section at Eneagu-Amuri where a-50 m – thick exposure occurs. The section is illustrated in Figure 3.

The member is composed of a basal siltstone and coarse-grained cross-bedded upper sandstone with occasional pebble beds. The basal deposit is a transitional facies and consists of light-gray siltstone and shale. It is occasionally

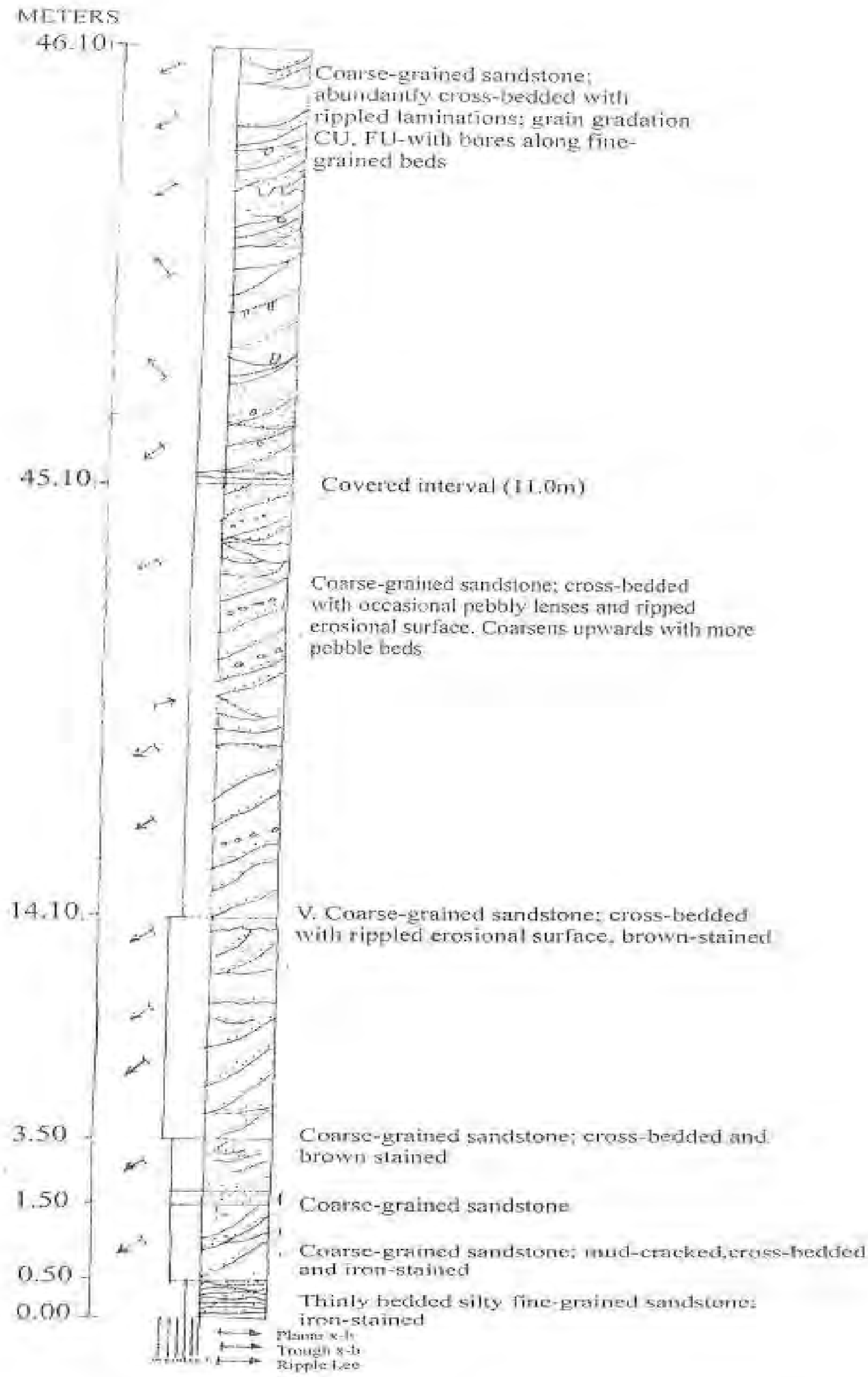

Figure 3: Log of Agbani Sandstone Type Section at Eneagu-Amuri

marked by sparsely fossiliferous silty limestone. The siltiness decreases upwards to predominantly fine-grained glauconitic sandstone with minor mottled shale laminae overlain by cross-bedded medium-to coarse-grained sandstone. The gradation upwards from shales through siltstone to cross-bedded sandstone represents a coarsening-upward (CU) succession. The increase in grain size upwards corresponds to increase both in the frequency of occurrence and set thickness of the cross-beds. Similarly, low-angle (10-15°) planar and bipolar sets change to high-angle (30-40°) curved sets or tabular cross-beds upwards. The cross-bed azimuths are highly varied with a regional vector of 250° and variance values ranging from 8,000-10,000 (standard deviation: 89.4° - 100°).

The Ogugu Shale: The clay mineral suites of the Ogugu Shale were studied through a combination of X-ray diffraction and wet chemical analysis. The clays were identified using the criteria set by Carroll (1970) and Brindley and Brown (1980). The clay types are mainly kaolinite (30%); smectite/illite (37%); smectite (17%); and illite (6%). The result of the chemical analysis of the clay is given in Table 1.The Al_20_3/ K_20, Al_20_3/ Mg0 and Mg0/ K_20 ratios are 12.27, 31.16 and 0.39, respectively. Similar ratios were used by Porrenga (1967) to interpret environments of deposition of various sedimentary deposits.

TABLE 1 - MODAL ANALYSES OF REPRESENTATIVE SAMPLES OF THE AGBANI SANDSTONE

SANDSTONE NO.	PERCENTAGE OF QUARTZ					PERCENTAGE OF FELDSPAR				OTHERS		
	UNDULOSE QUARTZ		NON-UNDULOSE QUARTZ		TOTAL QUARTZ				TOTAL FELDSPAR			
	Mono-crystalline	Poly-crystalline	Mono-crystalline	Poly-crystalline		Micro-cline	Ortho-clase	Plagioclase		Mica	Matrix	Cem.
419	30.2	4.69	30.00	1.43	66.62	1.25	11.01	23	13.87	0.1	-	-
417	31.71	2.098	38.18	1.09	73.09	1.05	-	-	1.05	0.10	7.57	8.20
418	22.72	2.22	33.10	0.91	95.05	2.72	8.19	1.23	12.34	0.42	19.11	9.20
421	28.28	3.84	48.29	1.30	81.71	3.14	6.00	1.13	10.29	-	9.0	2.90
442	22.78	1.74	33.43	-	67.78	1.11	9.00	3.11	14.10	0.20	14.95	8.82
444	16.48	-	26.10	-	42.58	3.88	22.70	3.38	28.98	0.25	18.50	11.27
437	34.48	1.38	42.10	-	78.74	3.15	10.31	1.80	15.46	2.25	3.43	2.51
440	32.86	3.86	41.28	1.01	77.71	3.17	8.42	1.25	12.14	0.11	8.84	3.19
436	28.39	3.15	30.42	1.21	62.17	3.41	16.70	1.20	20.31	0.60	11.11	5.81
432	30.82	1.20	40.17	-	72.19	1.07	2.15	1.03	4.25	0.51	15.75	7.80
AVERAGE	28.434	2.422	38.338	1.16	73.24	2.596	10.57	3.51	13.297	0.31	10.849	6.62

The Ogugu Limestone: Microfacies studies indicate that the limestone of the Ogugu Shale member is essentially a packstone-wackstone. It is composed of a polymictic assemblage of allochems of both whole and fragmented mollusks (e.g. *Tissotia awguensis, Turitella sp*.), and microfuanas (Figure 4a). The latter include the foraminifera*, Whiteinella baltica, Heterohelix striata* and *Nonionella robusta*, which were described by Petters (1980). Among the foraminifera are agglutinated forms (*Ammobaculites*, *Haplophragmoides*), while fish bones, echinoids, calcispheres, some algae and bryozoans occur. Other carbonate grains include ooids or peloids which were probably reworked, as indicated by their brown colouration and sharp contact with the matrix. Quartz, some pyrite and silt are the non-carbonate grains. The grain sizes range from less than 50 microns to more than 1.0 cm. The grains are poorly sorted with a roundness of between 0.3 and 0.5.; they constitute about 20% to 50% of the rock and are grain- and mud-supported.

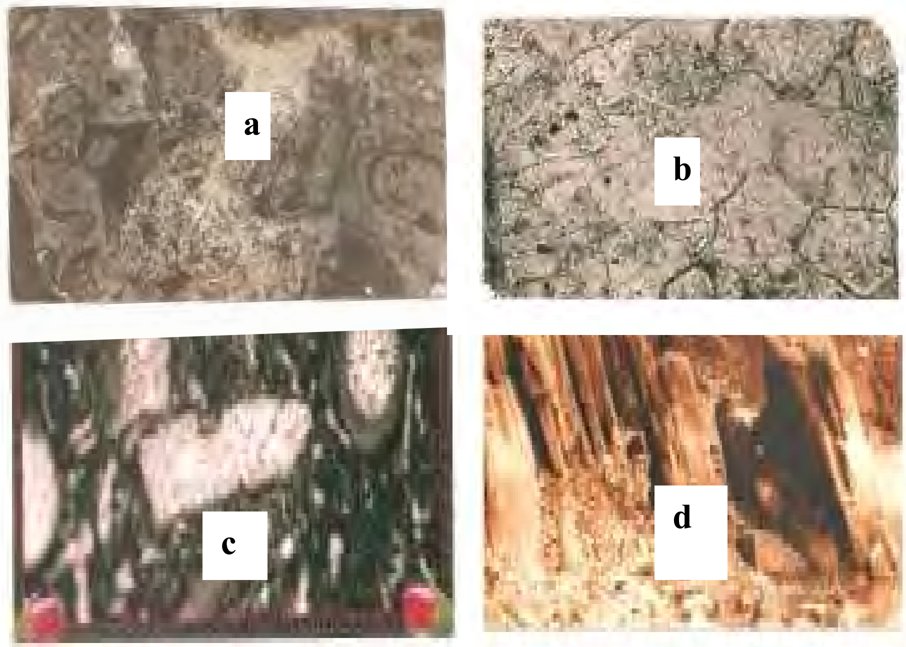

Figure 4:

a. Polymictic assemblage of allochems, mainly macro-and micro-faunas and geopetal silt due to dispersive pressure.
b. Coarse-crystalline (anhedral crystal) mosaic of sparry calcite with zircon inclusions.
c. Wholesale pseudo-sparitization and partial neomorphism of shell.
d. Sheared indurated mudstone owing to tight folding and associated cleavage in Abakiliki area in the Southern Benue Trough.

The matrix is essentially micrite. Cement occurs as sparry calcite in the interparticle and skeletal pore spaces. The cement is often clear with a coarsely crystalline and anhedral crystal mosaic. Crystal growth is usually marked by isopachous morphology while some inclusions of zircon occasionally occur (Fig 4b). Meyers (1978) interpreted similar inclusions as indicative of syndiagenetic high-Mg calcite. Diagenesis is alo demonstrable as wholesale psedo-sparitization and partial neomorphism (Fig 4c). X-ray diffraction analysis of the carbonate poweder indicates a fairly pure limestone with a Ca/ Mg ratio of 55. The residue is composed of fine-grained sands, silt and clay. The limestone belongs to Facies Zone (FZ) 7 of Wilson (1975).

The Agbani Sandstone: The cumulative curves of representative samples of the Agbani Sandstone are shown in Figure 5.

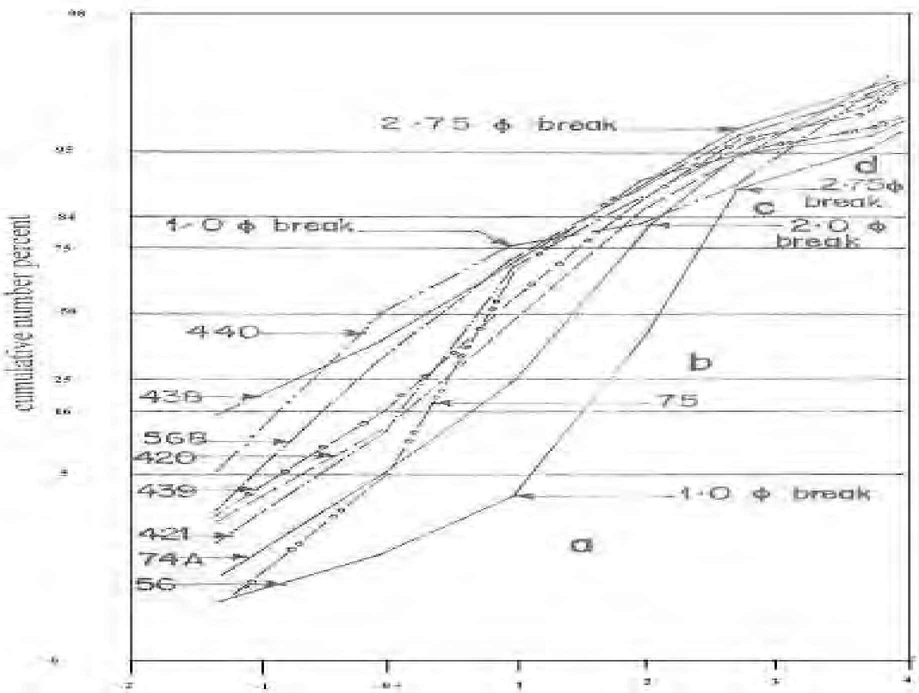

Figure 5 : Grain size distribution curves of the Agbani Sandstone illustrating the truncation of the curves into traction load (a), saltation load (b & c), suspension load (d)

Traction = 3% to 72%
Saltation = 3% to 95%
Suspension = 3% to 10%

The sandstone is composed of 3% to 72% traction load, 3% to 95% saltation load and 3% to 10% suspension load. The cumulative curves match the SG-FG-SG-KX and MG-KV-SA-KK of Sindowski (1957) and those of the shallow marine banks of Visher (1969, fig. 17 B & C). The linear discriminant functions based on the estimations by Sahu (1964) are as follows: ^{Y} eol: bc = 2.5103; ^{Y} shmar: fluv = 7.3293; ^{Y} fluv: tb = 6.8326.

Sahu (1964) used mathematical equations to distinguish between aeolian and beach; shallow marine and fluvio-deltaic; and fluvio-deltaic and turbidite environments. The equations are as follows:

1) ^{Y} eol: bch = -3.5688Mz + 3.7016ÓI^{2}- 2.0766SKI + 3.1136KG
2) ^{Y} bch: shmar = 15.6534Mz +65.7091ÓI^{2} – 18.1071SKI +18.5043KG
3) ^{Y} shmar: fluv = 0.2852Mz -8.7604ÓI^{2} - 4.8932SKI + 0.0482KG
4) ^{Y} fluv: turb = 0.7215Mz – 0.4030 ÓI^{2} + 6.7328SKI + 5.2927KG

Where (1) Mz = Graphic Mean
(2) $Ó_I$ = Inclusive Graphic Standard Deviation
(3) SK_I= Inclusive Graphic Skewness
(4) K_G = Graphic Kurtosis
(Folk and Ward 1957; Folk, 1968).

The grains are generally sub-rounded with occasional sub-angular components. The sphericity values range from 0.96 (very equant) to 0.43 (very elongate) with a mean value of 0.70 (sub-equant). The feldspar was generally more elongate with sphericity values ranging from 0.37 (very elongate) to 0.93 (very equant). The mean was 0.65 (sub-elongate). The cleavage direction of feldspar probably imparted the elongate shape on the feldspar grains.

The fabric relationship is generally concavo-convex with a few line contacts. The predominance of concavo-convex contacts may be a result of burial to depth exceeding 1,300 m where grain boundaries are usually smothered by pressure solution (Fuchtbauer, 1974). The chemical milieu of the Agbani Sandstone could have contributed to the development of pressure solution even at shallow depths (Adams, 1964). The latter may be due to the presence of clay mineral suites which Thompson (1959) ascribed to increased intergranular pressure solution on a local scale.

Quartz forms the major light mineral in the sandstone. It consists of 26-50% non-undulose and 16-35% undulose varieties (Table 2). Polycrystalline grains constitute 0.0-4.69% of the grains while the average total quartz content is about 69.64% (Table 2).

The average feldspar content is 13.30%. Among the feldspars are microcline grains some of which are degraded and filled with reddish limonite (Fig. 6a). The other feldspar species is plagioclase (oligoclase). The grains are altered to either a cloudy or grayish turbid appearance probably due to fluid-filled vacuoles resulting from weathering (James *et al*., 1981) or sericitic coated surfaces which correspond to the twin lamellae. The plagioclase-to-total feldspar ratio in the Agbani Sandstone is 1:15. Orthoclase grains are few and much altered to kaolinite (Fig 6b). Less than 0.5% of mica occurs in the sandstone. Glauconite occurs mostly as spheoidal and cemented sand-sized grains. Some degraded grains are like mica or sericite; or may occur as iron-oxide cement (Fig. 6c). The void fillers are mainly pseudomatrix-degraded feldspars and kaolinitic clay and iron-oxide commonly derived from degraded glauconite.

TABLE 2. ELEMENTS AND MAJOR OXIDES IN THE SHALES OF THE AWGU FORMATION

SAMPLES	Al	Ca	Fe	K	Na	Mg	Mn	Cr	Al_2O_3	CaO	Fe_2O_3	K_2O	Na_2O	MgO	MnO	Cr_2O_3
519	9.47	122	2.24	0.98	3394	4600	3413	101	17.89	0.02	7.02	1.28	0.46	0.76	0.38	0.02
*520	3.24	2.19	4.02	1.06	1902	3625	229	208	12.86	3.06	5.75	1.28	0.50	0.22	0.03	0.03
523	11.20	-	3.88	1.24	327	1300	80	105	21.17	-	5.58	1.25	0.84	0.2	0.01	0.02
361	13.45	-	1.89	2.30	2592	1527	108	116	25.42		2.70	2.55	0.44	0.26	0.09	0.02
503	10.49	72	2.44	1.40	1808	3959	346	103	19.82	0.07	6.35	1.69	0.24	0.66	0.04	0.02

9.47 (wt %)

125 (ppm)

* calcareus shale

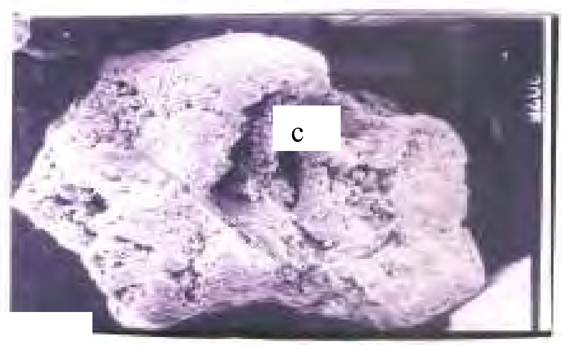

Figure 6:

a. Degraded microcline, iron-stained to reddish brown.
b. Altered orthoclase to kaolinite
c. Altered glauconitic to mica with iron-oxide cement

The Agbani Sandstone contains quartz (83.76%); feldspar (15.91%) and rock fragments (0.32%) and an average matrix content of 19-20%. It is mainly an arkosic wacke with minor quartz wacke and arkosic arenite. The heavy minerals consist of opaques (magnetite and limonite) and non-opaques (zicron, tourmaline, rutile, kyanite and anatase).

STRUCTURAL FEATURES

The Awgu Formation is gently to moderately folded and faulted in places (Fig 1.) The faults are recognized from LANDSAT images as the southern extension of *en echelon* lineaments which in the Upper Benue Trough (UBT) are arranged close to the margin of the trough and show no visible transcurrent displacement as against horizontal displacement of over 20 km in some parts of the trough. In the Southern Benue Trough, the fracture lineaments are perpendicular to the NE trending fold axis and probably initially formed complementary to the NE trending lineaments (Fig. 1; Orajaka, 1965; Agumanu, 1974, 1984; Chukwu-Ike, 1981). Chukwu-Ike (1981) observed that in the Middle Benue Trough (MBT) the lineaments could be normal faults which resulted during the Santonian deformation. They probably were formed in response to the release of pressure in a direction normal to the rocks during the dying stages of the deformation (Orajaka, 1965).

The fractures are sometimes open and filled with well-formed calcite crystals as occur at Ndeaboh near Awgu. This agrees with Farrington's (1952) observation from Abakaliki area in the Southern Benue Trough that mineralization occurred dominantly as open-space filling within *en enchelon* tensional, steeply dipping fracture system (Olade, 1975).

The fractures transect numerous northeast-southwest trending fold axes. The folds are gentle in both the Middle and Northern Benue Troughs (Cratchley and Jones, 1965) probably due to more intense deformation which affected the Southern Benue Trough (Nwachukwu, 1972).

The folds are arranged *en echelon* parallel to the trough axis. The arrangement suggests sinistral movement along NNE shear faults. The shearing effect resulting from such faults are as observed in Abakaliki area (Fig 6d). The shear deformation, according to Benkhelil *et al*. (1989), resulted from tight folding with associated cleavage arising from a N150°E-trending compression of the Santonian age. The crystalline Basement counterpart occurs probably at the Kaltungo inliers (Benkhelil *et al*., 1989).

According to Cratchley and Jones (1965), the following sequence of events took place in the Southern Benue Trough and probably in other parts of the basin: earth movement-folding –minor fracturing –intrusives – mineralization.

The dips of strata of the Awgu Formation are shallow (5° -10°) to occasionally steep (15° -36°). The latter occur near the fold axes because of stratal deformation (Fig 1). Orajaka (1965) confirmed a similar relationship in Enyigba, Ameri and Ameka areas of Abakiliki in the Southern Benue Trough. The implication is that the Awgu Formations was probably uplifted and eroded due to the Santonian structural deformation, folding and uplift of the Southern Benue depression (Murat, 1972; Nwachukwu, 1972).

DISCUSSION

Inferences on the environment of deposition of the Awgu Formation have, hitherto, been based on faunal evidence. It was on the basis of rich marine faunas recovered from the shale that Perch-Nielsen and Petters (1981) suggested a deep marine environment for the formation. The environmental significance of the major sedimentary features of the Awgu Formation concluded from the present study is summarized in Table 3 and discussed below.

The characteristic well-bedded, smooth, blue-gray shale and biosparite lithofacies with occasional pyrite and gray-black shales is comparable with that interpreted by

TABLE 3. ENVIRONMENTALLY DIAGNOSTIC CHARACTERISTICS OF THE AWGU FORMATION

FEATURES	ENVIRONMENT	REFERENCE
Well- bedded, blue–grey, smooth shale: becomes sandy and pyretic and grey–black towards the bottom.	Marine deposit with occasional anoxic level.	Heckle (1972); Petters (1978).
Smectite/ illtite, illite, kaolinite, maximum occurrence of smectite	Presence of marine deposit; warm and humid climatic condition	Hower *et al*. (1976, Chamley *et al*. (1979).
Al_2O_3/K_2O: high; Al_2O_3/MgO:low; MgO/K_2O: high	Marine condition	Porrenga (1967); Hower *et al*.(1976).
High total organic carbon content	Shallow marine	Petters and Ekweozor (1982).
Limestones, mainly wackestone-pack stone with high fossil content including ammonites, gastropods, pelecypods, fish bones, foraminifers	Hollomarine mixed with shallow bottom deposits. Carbonate facies zone (F Z) = 7; platform areas in shallow seas	Heckle (1982), Petters (1978a); Perch – Nielsen Petters (1981); and Wilson (1975), Flugel (1982).
Borings in ooids	Shallow marine conditions with good tidal exchange	Garber et al, (1981).
Weathered grpsum in the formation	Local development of evaporite facies in shallow anoxic bottom	Heckel (1972).
Sandstone, cross-bedded, coarsens upwards from siltstone base.	Regressive sequence: Shallowing of the sea	Brenner and Davies (1974.

High angle, planar to tabular cross-beds	Deltaic deposition	Owens and Shol (1971).
Cumulative curves conform with the SG-FG, SG-KX and MG-KV-SA-KK of Sindowski (1957)	Shallow marine	Sindowski (1957); Visher (1969); Amaral and (1977) Pryor.
Sahu's (1964) linear discriminant function: Yeo: Bch = 2.5103	Shallow marine	Sahu (1964).
Yshmar: fluv. = 7.3293	Deltaic	Sahu (1964)
Fine-skewed with marginal positives skewness: 0.88	Marginal marine zone: fluvial	Martin (1965); Folk (1966); Wallace (1976); Amaral and pryor (1977);
Feldspar is finer-grained than quartz	Deep burial under brakish or normal sea water	Wallace (1976);
X-bd azimuth variance 8,000-10,000 (s.d = 89.4^0.100^0) mean direction 250^O (N = 33)	Fluvio-deltaic: **marine**	Potter and Pettijohn (1977).

Heckle (1972) and Potter *et al.* (1980) among others to suggest marine deposition with occasional anoxic levels. Petters and Ekweozor (1982) suggested 30 m water depth for the Turonian – Coniacian Agwu Formation based on benthic diversities in the black shales. Shallow depths of deposition are also indicated by calcarenites and bioturbated shallow-water subtidal sandstones which Petters and Ekweozor (1982) found commonly to intercalate with the shales. Besides, shallow near-shore setting is inferred from the restricted marine cocolith *Watznaueria bernesae* (Perch Nielsen and Petters, 1981) recorded from the formation. The wackestone-packstone which denotes a platform carbonate deposit with open ciculations and tropical condition (Flugel, 1982) suggest shallow marine environment for the Awgu Formation.

Carbonate platforms are veritable indicators of shallow depths not unless they are affected by rift tectonics , flexural subsidence and subsequent drowning or eustatic sea level rise (Drzeweicki and Simo, 2000). Our study indicates that any probable eustatic sea level rise and flooding of the Southern Benue Trough in the Coniacian (Reyment, 1980) was drained during the Santonian deformation, uplift and erosion of the Benue depression (Murat, 1972).

The sandstone geometry (length = 40 km; width = 10 km; exposed thickness = 45 m) and high percentage (approx. 90%) of sand are similar to the feature of shallow marine deposits suggested by Walker (1979; table 1). Coarsening-upwards (CU) succession and occasional pebbly deposits sandwiched between shales are similar to the features used by Brenner and Davies (1974), among others, to indicate a regressive phase and a shoaling of the sea. According to Walker (1979, p. 84), such a coarsening-upward motif probably resulted from the transportation of fine sediment in the down current direction or is due to the upward-building epochs which usually consist of basal shale followed by non-deposition and terminating with siltstone and sandstone (Harms *et al.*, 1982). This model agrees with the deposition of the sequence of the Awgu Formation (Fig 7).

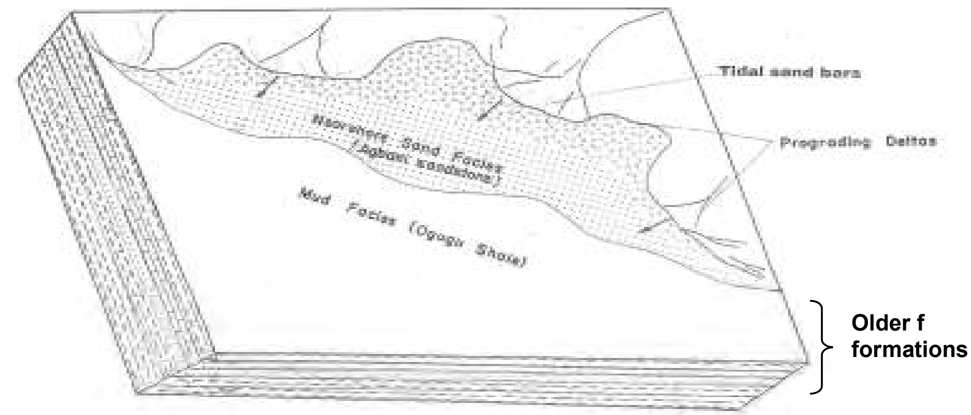

Figure 7: Depositional model for the Awgu Formation (Adapted from Brenner and Davies, (1974).

There is, however, no break in sedimentation between the limestone and the Agbani Sandstone probably because of a gradual regression after a rise in sea level in the Coniacian (Petters, 1978; Reyment, 1980). Unlike offshore marine sandstone, suspension clays are absent while glauconite is more abundant in the subjacent fine lithologies. Glauconite occurrence is one of the indicators of reduced sedimentation rate, typical of transgressive surfaces. Together with coarse bioclastic limestone, shallow depositional environment is inferred (Bauer *et al*., 2003). Clay laminae are rare to absent confirming energetic depositional processes characteristic of a near shore sand body. Shoaling is also suggested by the upward increase in the frequency of occurrence, angle of dip and thickness of beds. This is attributable to increased wave action in a near shore environment of deposition (Harms *et al*., 1982) and is supported by the varied azimuths of cross-beds. The variance (8,0000-10,000) and standard deviation (89.4-100) are those typifying hallow marine sandstones (Potter and Pettojohn,1977). The wave form was invariably oscillatory in view of the bipolar cross-beds attributable to tidal currents as illustrated in Figure 8.

Although Perch-Nielsen and Petters (1981) suggested a deep marine environment of deposition for the Awgu Formation, the agglutinated foraminifers, gastropods and pelecypods indicate shallow water. Petters (1983) in a later study indicated a mid-Cretaceous widespread marine transgression which favoured the development of an anoxic epeiric sea with marshes and coal swamps in the Benue Trough. Increased shoaling is further indicate by the large accumulation of randomly oriented shells of *Exogyra* while planktonic foraminifers were pyritised due to waning marine influence accompanied by periodic depletion of oxygen. The thin beds of leached evaporite facies also confirm shallow anoxic bottom

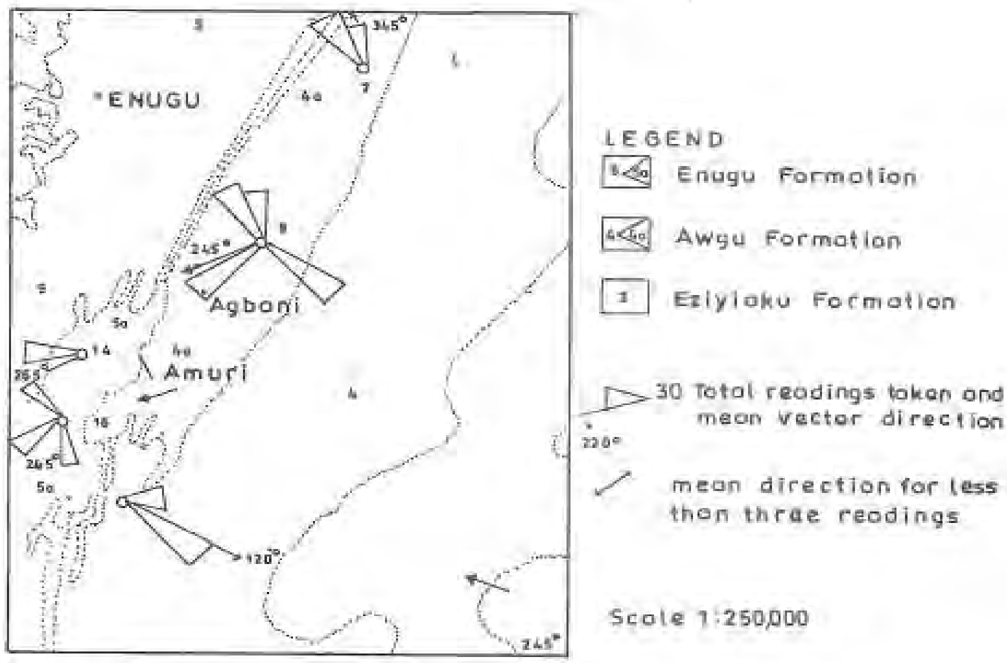

Fig 6: Paleocurrent map of the Awgu Formation, southern Benue Trough

Petrologically, the clay mineral suites - smectite /illite and smectite –and the Al_2O_3 / K_2O (12.25), Al_2O_3/ MgO (13.16) and MgO / K_2O (0.39) ratios indicate a marine environment for the formation. The high percentage of total organic carbon recorded from the shale by Petters and Ekweozor (1982), suggested a shallow marine environment of deposition. The depth probably did not exceed 50 m in view of the glauconite present. The average sorting (Ó = 0.88) of the sandstone is close to fluvial or shallow marine deposition (Folk, 1966; Amaral and Pryor, 1977). The linear discriminant function accords with the values used by Sahu (1964) to detect shallow marine or deltaic conditions. The shallow marine aspect is well established from faunas and glauconite while the deltaic influence is probably due to continued progradation and subsequent development of tidal sand bars.

The latter is further suggested by the cumulative curves which match the SG-FG SG – KX and MG-KV-SA- KK types of Sindowski (1957). Similar curves have been used by Amaral and Pryor (1977) to infer a shallow marine environment of deposition.

Shallow marine is predicated upon the Santonian deformation - folding, uplift and erosion of the Southern Benue Basin (Murat, 1972; Nwachukwu, 1972). These events exposed the Awgu Formation to slightly acid and exhaustive leaching conditions which favoured both kaolinitization at source and differential exposure of the marine clays to the above conditions.

CONCLUSION

The data on lithology, faunas, texture, petrology and structure warrant the following conclusions on the paleogeographic history of the Awgu Formation:

1) The formation is a progradational sequence of shale, siltstone and sandstone deposition in a shallow environment;
2) The coarsening-upward (CU) succession of fairly well-sorted and cross-bedded sandstone with occasional pebble beds without clay laminae is typical of shoreline deposition;
3) The depositional current was strong, very diverse and oscillatory, typifying tidal currents with occasional probable energetic depositional processes such as storm waves;
4) The unit was deposited at a shallow depth (not more than 50 m) generally under open marine influence with occasional foul or oxygen-deficient levels; and
5) The formation was tectonically deformed, uplifted and eroded such that it is now a remnant of the sediments of the third depositional cycle in the Benue Trough

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REFERENCES

Adams, W.L., 1964. Diagenetic aspect of the Flower Morrowan, Pennysylvanian Sandstone, north-western Oklahoma Bull. Amer. Assoc Petrol. Geol, 48, 568-1580.

Agumanu, A.E., 1974. Geological Map of Sheet 215 (Jalingo): Unpl. Field Map. Geo, Surv. Nig. Scale 1:100,000

Agumanu, A.E., 1984. Geological Map of Sheet 302 (Nkalagu): Unpl. Field Map, Geo, Surv. Nig. Scale 1:100,000

Amaral, E.J. and PRYOR, W.A., 1977. Depositional environment of the St. Peter Sandstone deduced by textural analysis. Jour.. Sed. Petrol. 47, 32-52.

Avbovbo, A.A. and Ogbe , F.G.A., 1978. Geology and Hydrocarbon productive trend of southern Nigeria basin. Oil and Gas Journal, 76, (48): P. 90-93.

Baird, G.G., 1978. Pebbly phosphate in shale: A key to recognition of a widespread submarine discontinuity in middle Devonian of New York. Jour. Sed. Petrol, 48, p. 545-556.

Bathurst, R.G.C., 1991. Pressure dissolution and limestone bedding; the influence of stratified sedimentation. In: Einsels, et al. (Eds.); Cycles and events stratigraphy, Springer-Verlag Berlin Heidelberge pp 450-463.

Bauer, J., Kuss, J. and Steuber, T., 2003. Sequence architecture and carbonate platform configuration (Late Cenomanian-Santonian) Sanai Egypt. Sedimentology, 50, 387-414.

Benkhelil, Guirid, M., Pondard, J.F. and Saugy, L., 1989. The Bornu-Benue Trough, the Niger Delta and its offshore: tectono-sedimentary reconstruction during the Cretaceous and Tertiary from geophysical data and geology. In: Kogbe, C.A. (Ed.): Geology of Nigeria. Rock View (Nig.) Ltd., pp. 277-309.

Brenner, R.L. and Davies, D.K., 1974. Oxfordian sedimentation in Western Interior United States. Bull. Amer. Assoc. Petrol. Geol., 68, 407-428.

Brindley, G.W. and Brown, G., 1980 (Eds): Crystal structure of clay minerals and their X-Ray identification. Mineralogical Society Monograph No. 5 Min Soc. London, 495p.

Carroll d, 1970. Clay minerals: a guide to their X-ray identification, Geol. Soc. Amer. Special paper, 120.80p.

Carter, J.D., Barber, W., Tait, E.A. and Jones, G.P., 1963. The Geology of parts of Adamawa, Bauchi and Bornu Provinces in northern Nigeria. Bull. Geol. Surv. Nigeria, 30, 109P.

Chukwu-Ike, I., 1981. Marginal Fracture System of the Benue Trough in Nigeria and their tectonic implications. In: Vogel, A. (Ed-in-Chief): Earth Evolutionary Science 2, 104-109.

Cratchley C.R. and Jones G.P., 1965. An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria. Overseas, Geological Survey, Geophysical Paper No. 1. Her Majesty's Stationery Office, Printers Limited, 22p, I map.

Dessauvagie, T.F.J., 1974. Geological Map of Nigeria: Nig. Min. Geol. Metallurgical Soc., Scale, 1:1,000,000.

Drzewiecki, P.A. and Simo, J.A.C. (Toni), 2000. Tectonic, eustatic and environmental controls on mid-Cretaceous carbonate platform deposition, south-central Pyrenes, Spain. Sedimentology, 47, 471-495.

Farrington, J.L., 1952. A Preliminary description of the Nigerian Lead-Zinc Field. Bull of the Society of Econ. Geol. (6): P. 583-608.

Fauchtbuer, H., 1974. Sediments and Sedimentary rocks. John Wiley and Sons, Inc. 464p.

Flugel, E., 1982. Microfacies analysis of limestones (Translated by K Christenson). Springier-Verlag, 633p

Folk, R.L., 1966. A review of grain size parameters. Sedimentology, 6, 73-93.

Garber, R.A., Friedman, G.M. and Nissenbaum, A., 1981. Concentric aragonitic ooids from the Red Sea. Jour. Sed. Petrol.. 51, 455-458.

Hamley, DE H., Enu, E.I., Moullade, M and Robert, C., 1979. La sedimentation da basin la Benoue an Nigeria, reflect de la tectonique du cretare superieur. C.R. Alad. Sc. Paris, t. 288 series D-1146.

Harms, J.C., Southward, J.B. and Walker, R.G., 1982. Structures and sequences in clastic rocks. SEPM Short Course No. 9. 249 p

Heckel, P.H., 1972. Recognition of ancient marine environment. In: Rigby, J.K. and Hamblin, W.K. (Eds.) Recognition of ancient sedimentary environments SEPM spec. publ. No. 16. p. 226-286.

Hoque, M., 1977. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycle, southern Nigeria. Sed. Geol. 17, 235-245

Hower, J., Elsinger, E., Hower, M. and Peng, E., 1976. The mechanism of diagenetic reaction in argillaceous sediments, I. Mineralogical and chemical evidence. Geol. Soc. Amer. Bull., 87,725-737.

James, W.C., Mack, G.H. and Suttner, L.J., Relative alteration of microcline and sodic plagioclase in semiarid and humid climate. Jour. Sed. Petrol., 51, 151-164.

Marmo, V., 1971. Granite Petrology and the Granite Problem. Amstedam, Elsevier Publ, Comp., 244p.

Meyers, W.J., 1978. Carbonate cements: Their regional distribution and interpretation in Mississipian limestone in southwestern New Mexico. Sedimentology, 20, 371-400.

Moila, L.R. 1965.Significance of skewness and kurtosis in environmental interpretation. Jour. Sed. Petrol. 35, 768-770.

Offodile, M.E. and Reyment, R.A., 1977. Stratigraph of the Keana- Awe of the middle Benue Region of Nigeria, Bull. Geol. Inst. Univ. Uppsala, New 7, 37-66.

Olade, M.A., 1975. Evolution of Nigeria's Benue Trough (Aulacogen): a tectonic model. Geol Mag., 112 (6): pp 575-583.

Orajaka, A.S., 1965. The geology of Enyigba, Ameri and Ameka lead-zinc lodes, Abakiliki Division Eastern Nigeria- A Reconnaissance. J. Min. Geo. 2 (2): PP 65-70.

Owens, J.P., and Sohl, N.Z., 1971. Shelf and deltaic paleoenvironments in the Cretaceous –Tertiary formations, New Jersey Costal Plain. U.S. Geol. Surv. Field Trip. (2): p. 235-278.

Pierch-Nielsen, K. and Petters, S.W., 1981. Cretaceous and Eocene microfossils ages from southern Benue Trough, Nigeria, Arch. Sc. Genese, 34 m 211-218.

Petters, S.W. and Ekweozor, C.M., 1982. Origin of micaceous black shales in the Benue Trough, Nigeria, Palaeogeo. Palaeoclim. Palaeocol., 40, 311-319.

Petters, S.W., 1983. Littoral and anoxic facies in the Benue Trough, Bull. Centres. Rech. Explor. Prod. Elf Aquitaine, 7, (1): 361-365,

Porrenga, D.H., 1967. Clay mineralogy and geochemistry of recent marine sediments in tropical areas. Publicaties Var ler Fysich Geografisch Laboratorium van de Universiteit van Amsterdam, 9p.

Potter, P.E. and Pettijohn, F.J., 1977. Paleocurrent and basin analysis. Berlin, Springer –Verlag

Potter, P.E., Maynard, J.B. and PRYOR, W.A., 1980. Sedimentology of shales. New York, Springer-Verlag, 306p.

Reyment, R.A., 1965. Aspects of the geology of Nigeria. Ibadan Univ. Press, 146p.

Reyment, R.A., 1980. Biogeography of the Saharan Cretaceous and Paleocene Epicontinental Transgression. Cretaceous Research, 1, 22-327.

Sahu, B.K., 1964. Depositional mechanics from size analysis of clastic sediments. Jour Sed Petrol 34, 73-83.

Simpson, A., 1954. The Nigerian Coal field: the geology of parts of Owerri and Benue Provinces. Bull. Geol. Survey Nigeria. (24):.

Sindowski, K.H., 1957. Die Synoptischs methode des Kor Inkurven-vergleiches Zur Audentung fossiler sedimentatiosranme. Geologisches Jahrbuch 73:235-275.

Thompson, A.F., 1959. Pressure solution and porosity. In: Ireland, H.A. (Ed.). Silica in sediments SEPM Special paper (71): 85p.

Visher, R.G., 1976. Grain size distribution and depositional processes. Jour. Sed. Petrol., 39, 1074-1160.

Walker, R.G., 1979 (Ed.). Facies Models. Geoscience Canada Reprint Series, 1, 211p.

Wallace, C.A., 1976. Diagenetic replacement of feldspar in the Unita Mountain Group, Utah, and its geochemical implications. Jour. Sed. Petrol. 46, 846-861.

Wilson, M.E.J., Bosene, D.W.J and Libong, A., 2000. Syntectonic carbonate platform development, Indonesia. Sedimentology, 47, 395-419.