ENVIRONMENT OF DEPOSITION OF THE AWGU FORMATION (LATE CRETA CEOUS), 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 Agban 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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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.

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**Figure 1: Geological map of part of the Southern Benue Trough showing the Awgu Formation and other lithologic units.**
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 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 Aghani 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-beded 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 Al₂O₃/ K₂O, Al₂O₃/MgO and MgO/ K₂O 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.

**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 microfanaus (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*, *Hapiophragmoides*), 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.
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 also demonstrable as wholesale pseudo-sparitization and partial neomorphism (Fig 4c). X-ray diffraction analysis of the carbonate powder 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.
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: \( Y_{eol}^bch = \frac{2.5103}{b} \) ; \( Y_{shmar}^{fluv} = 7.3293 \); \( Y_{fluv}^bch = 6.8326 \).

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) \( Y_{eol}^bch = -3.5688Mz + 3.7016\Omega I^2 - 2.0766SKI + 3.1136KG \)
2) \( Y_{bch}^{shmar} = 15.6534Mz + 65.7091\Omega I^2 - 18.1071SKI + 18.5043KG \)
3) \( Y_{shmar}^{fluv} = 0.2852Mz - 8.7604\Omega I^2 - 4.8932SKI + 0.0482KG \)
4) \( Y_{fluv}^{turb} = 0.7215Mz - 0.4030\Omega I^2 + 6.7328SKI + 5.2927KG \)

Where (1) \( Mz \) = Graphic Mean
(2) \( \Omega I \) = Inclusive Graphic Standard Deviation
(3) \( SKI \) = Inclusive Graphic Skewness
(4) \( KG \) = 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. Glaucnite occurs mostly as spheroidal 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

<table>
<thead>
<tr>
<th>SAMPLES</th>
<th>Al</th>
<th>Ca</th>
<th>TiO2</th>
<th>SiO2</th>
<th>Mg</th>
<th>FeO</th>
<th>K2O</th>
<th>Na2O</th>
<th>MnO</th>
<th>Cr</th>
<th>P2O5</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>MgO</th>
<th>Na2O</th>
<th>K2O</th>
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<tr>
<td>919</td>
<td>2.41</td>
<td>7.61</td>
<td>2.25</td>
<td>1.04</td>
<td>0.89</td>
<td>2.06</td>
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<td>0.50</td>
<td>0.03</td>
<td>0.09</td>
<td>0.30</td>
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<td>920</td>
<td>2.14</td>
<td>7.71</td>
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<td>0.98</td>
<td>0.50</td>
<td>0.03</td>
<td>0.09</td>
<td>0.30</td>
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<tr>
<td>123</td>
<td>2.26</td>
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<td>2.14</td>
<td>1.07</td>
<td>0.87</td>
<td>2.05</td>
<td>0.98</td>
<td>0.50</td>
<td>0.03</td>
<td>0.09</td>
<td>0.30</td>
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<td>124</td>
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<td>7.85</td>
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<td>1.07</td>
<td>0.87</td>
<td>2.05</td>
<td>0.98</td>
<td>0.50</td>
<td>0.03</td>
<td>0.09</td>
<td>0.30</td>
<td>0.02</td>
<td>0.02</td>
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<td>125</td>
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<td>0.50</td>
<td>0.03</td>
<td>0.09</td>
<td>0.30</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
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</tbody>
</table>

* Calciteous 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 (zircon, 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 echelon* 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 Depression (Nwachukwu, 1972).

<table>
<thead>
<tr>
<th>FEATURES</th>
<th>ENVIRONMENT</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-beded, blue-grey, smooth shale becomes sandy and pyritic grey-black towards the bottoms.</td>
<td>Marine deposit with occasional anoxic level</td>
<td>Heckel (1972); Petturs (1978).</td>
</tr>
<tr>
<td>Smectite illite, illite, kaolinite, maximum occurrence of smectite.</td>
<td>Presence of marine deposit; warm and humid climatic condition</td>
<td>Hower et al. (1976); Chamley et al. (1979).</td>
</tr>
<tr>
<td>AsO₄/K:0.1; high; AsO₄/MgO:low; MgO/Si:high.</td>
<td>Marine condition</td>
<td>Forrengs (1967); Hower et al. (1976).</td>
</tr>
<tr>
<td>Limestonaceous, mainly wackestone-packstone with high fossil content, including ammonites, gastropods, pelecypods, fish bones, foraminifers</td>
<td>Halimarine mixed with shallow bottom deposition</td>
<td>Heckel (1982); Petturrs (1978a); Perch-Nielsen Petturs (1981); and Wilson (1975); Elfgel (1982).</td>
</tr>
<tr>
<td>Borells in silts</td>
<td>Shallow marine; conditions with good tidal exchanges</td>
<td>Harber et al. (1981).</td>
</tr>
<tr>
<td>Weathered gypsum in the formation</td>
<td>Local development of evaporite facies in shallow anoxic bottom</td>
<td>Heckel (1972).</td>
</tr>
<tr>
<td>Sandstone, cross-beded, cross-lamination upwards from alluvial to marine</td>
<td>Regressive sequence; shallowing of the sea</td>
<td>Tremper and Davies (1974).</td>
</tr>
</tbody>
</table>
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 coccolith Watznaueria bernesae (Perch Nielsen and Petters, 1981) recorded from the formation. The wackestone-packstone which denotes a platform carbonate deposit with open circulations 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 (Drzewiecki 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 (Mural, 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).
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 Pettijohn, 1977). The wave form was invariably oscillatory 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

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Petrologically, the clay mineral suites - smectite / illite and smectite - and the $\text{Al}_2\text{O}_3 / \text{K}_2\text{O}$ (12.25), $\text{Al}_2\text{O}_3 / \text{MgO}$ (13.16) and $\text{MgO} / \text{K}_2\text{O}$ (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 ($\bar{Q} = 0.88$) 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 acidic 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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