International Research Journal of Geology and Mining (IRJGM) (2276-6618) Vol. 5(3) pp. 31- 45, August, 2015
DOI: http://dx.doi.org/10.14303/irjgm.2015.116
Available online http://www.interesjournals.org/irjgm

Full Length Research Paper

Sedimentology of Conglomeratic Beds within Odoro Ikpe – Arochukwu Axis: Afikpo Basin Southeastern Nigeria

Ideozu R. U[1] and Ikoro D. O*[2]

[1]Department of Geology, University of Port Harcourt
[2]Deprtment of Geology, Federal University of Technology Owerri

***Correspondence Author's email**: ikorodiugo@gmail.com; ikorodiugoo@gmail.com

ABSTRACT

The conglomeritic outcrop sections at Odoro Ikpe along Arochukwu axis southeastern Nigeria were studied for their petrographic and morphometric attributes and have been used to settle the controversies on the origin and depositional environment of the conglomeratic beds in the Odoro Ikpe and environs. The area is located along longitudes 7°44'E - 8° 03'E and latitudes 5° 15 N - 5° 28'N within the transition zone between the Niger Delta basin and Afikpo Basin southeastern, Nigeria Petrographic and optical evidence show that the pebbles of the conglomeratic beds have a metamorphic origin. The pebbles are weakly foliated and dominated by inequant grains orientated in preferred directions. The study reveals that the conglomerates were deposited in a fluvial environment as maximum sphericity index values averages 0.66, form is dominantly compact bladed and clast is rod shaped.

Keywords: Odoro Ikpe, Arochukwu, maximum sphericity index, conglomerate, clast, rod shaped

INTRODUCTION

The origin of pebble beds found within and outside the study area has been a subject of controversy, and two schools of thought have emerged. One school of thought believes that the pebbles within the pebble beds have a sedimentary origin whereas the other school of thought believes it has magmatic origin. Rahaman (1988) observed that rocks of sedimentary origin in the Basement Complex are represented by horizons of medium to high-grade calcareous pelitic and quartzitic rocks - these are ancient metasediments of Oyawoye (1964). But Amajor (1986), in his classical work on the pebbles found around Itu and Odukpani, described these pebbles as quartz-pebble conglomerates comprising four facies. Petters (1989) suggested that the sand/gravel facies of Amajor (1986) form part of the Ogwashi – Asaba and the older Benin Formations because of uncertainty in the lithologic boundary between the two formations. Previous studies relating to the pebble belt suggest that these pebbles belong to the Ogwashi – Asaba Formation (Simpson, 1954; Reyment, 1965; Avbovbo, 1978; Udo, 2004 and Otu, 2005). Simpson (1954) observed that the Benin Formation extends to the south and southeast of Arochukwu. Another area of disagreement among many workers on the pebble belt area is the environment of deposition. Two schools of thought have also emerged. The first school of thought believes that the pebble beds were deposited in an alluvial fan environment (Simpson, 1954; Reyment, 1965; Avbovbo, 1978; Amajor, 1986) whereas the second school of thought believes that they were deposited in a fluvial (braided) environment (Petters, 1989; Inyang, 2001, 2010; Udo, 2004).

Detailed morphometric analysis by Petters (1989), suggests a fluvial origin for the pebble belt, because according to him the major fault trend (N-S) do not conform to the NE-SW trend of the conglomeratic beds and this negates the alluvial fan origin of the pebble beds

(Amajor, 1986), because alluvial fan deposition requires confinement of structural features or ancient mountain front (Rust, 1979). Inyang (2001) and Inyang and Enang (2002) using lithofacies analysis, morphometrics and grain size analysis suggested that these deposits have a fluvial origin. For modern gravels, pebble shapes provide additional indicator of the environment of deposition. Classical work on pebbles include those of Sneed and Folk (1958) on pebble morphogenesis and Luttig (1962) on pebble shape of continental, fluvial and marine facies. Dobkkin and Folk (1970) noted that first cycle beach gravels tend to be discoidal whereas fluvial gravels are rod-shaped. They concluded that a maximum projection sphericity (MPS) value of 0.66 and oblate prolate index (OPI) of more than 1.5 distinguishes beach from fluvial pebbles. They also suggested that a plot of MPS vs OPI distinguished fluvial from beach pebbles. This will be applied to determine the environment of deposition of these pebbles and attempt a resolution of the depositional environments for the pebble beds in the study area.

Tectonics and Structural Framework

The origin of Benue Trough is related to the separation of the African and the South American plates during the Cretaceous. The Benue Trough was left as an aulacogen, in which sediments were deposited (Burke et al., 1971; Olade, 1975). Reconstruction by Murat (1972) has suggested that the southern part of the Benue Trough was a longitudinally faulted basin with its eastern half subsiding to become the Abakaliki depression. Basin subsidence and deposition of sediments in the southern Benue Trough was high during the Albian times and low during the Cenomanian times. Sedimentation was restricted to the Calabar area before the regression and thermo-tectonic event that occurred during the Santonian times. According to many workers, this thermo- tectonics is related to the initiation of the formation of the Afikpo Basin and Anambra Basin. All Pre-Santonian beds were folded, faulted, and uplifted to form the Okigwe-Abakaliki Anticlinorium trending NE-SW. Murat (1970), identified three major structural cycles in southeastern Nigeria:

1. The Aptian – Early Santonian, related to the initial rifting of the southern Nigerian continental region and opening of the Benue Trough. This phase produced two principal sets of faults trending NE – SW and NW – SE. The NE – SW set of faults bound the Benue Trough, while the NW – SE deformed sedimentary beds within the Calabar Flank.
2. The Turonian – Santonian, which was characterised by compressional movements resulting in the folding of the Abakiliki Anticlinorium formation of the Anambra Basin and the development of the complementary Afikpo Syncline (Basin).
3. The Late Campanian – Middle Miocene phase, which produced rapid subsidence and uplift in alternation with subsequent pro-gradation of a delta.

Stratigraphic Framework

The stratigraphic history of Lower Benue Trough according to Short and Stauble (1967), Murat (1972) and Obi et al., (2001) is characterized by three main sedimentary phases which are the Abakiliki – Benue phase (Aptian -Santonian), the Anambra – Benin phase (Campanian – Mid Eocene) and the Niger Delta Phase (Late Eocene - Pliocene). Majority of the sedimentary beds were deposited in a NE – SW direction with a fining upward sequence whereas others were deposited in a NW-SE direction with a coarsening upward sequence. The Anambra-Benin phase ranginging from Campanian - Mid Eocene comprises these stratigraphic units- Nkporo Shale (Campanian), Mamu Formtion (Late Campanian - Maastrichtian), Ajali Sandstone (Maastrichtian), Nsukka Formation (Late Maastrichtian-Danian), Imo Shale (Eocene), Ameki/ Nanka Formation Paleocene) and the Oligocene Ogwashi-Asaba Formation. The pale ocurrent analysis of the cross-bedded sandstones in the Benue Trough suggests two separate provenances, which includes the northeastern source probably from the Hawal Massif and a northwestern source possibly from the Nigerian Basement Complex (Chikani et al., 2010).

Imprints of tectonism on the sediments in the Lower Benue Trough area are preserved by series of joints trending NW-SE. The ranges of depositional environment typical of the Lower Benue Trough especially within the Afikpo Basin are marine, continental, and transitional represented by the Asu River Group, Eze-Aku Group, Nkporo, Mamu, Ajali, Nsukka, Imo, Ameki Formations, Nanka Sands and Benin Formation (Table1).

MATERIALS AND METHODS

The methodologies applied for this research are standard methods as applied in field mapping, sedimentology, biostratigraphy and sedimentary petrology. The research study involved detailed fieldwork, petrography of pebbles, and pebble morphometric studies, based on samples and data collected during the field mapping. The spot sampling method was adopted for data collection during the field mapping exercise (Davies, 1973). Attention was given to accurate and detailed lithologic description and recording of parameters such as sedimentary structures, rock type and composition, biogenic structures, measurements of bed thickness, lateral extent of the outcrops in addition to information from measurement of strike and dip and geographic positioning system (GPS). Detailed lithologic descriptions were done for outcrops and informal nomenclature such as L1S1 was used for samples or facies.

Fieldwork

Detailed field mapping was undertaken to map the study area. The approach used was to document and describe the outcrops in detail to avoid a return or repeat of the field mapping exercise in addition to methods modified from Miall (1984), Tucker (1988) and Reijers (1996). Equipment used during the field mapping exercise include compass/clinometers, GPS, measuring tapes, strong sample bags and sacks properly labeled, cello tapes, field notebook, camera, protective clothing and strong boots in addition topographic map indicating the position of the study area (Ikot-Ekpene sheet 322 on a scale 1: 50,000). The outcrops identified were examined for bedding contacts, bed thickness variation, sedimentary and biogenic structures as well as syn- and post- depositional structures.

Petrography

Eighty five (85) pebbles were prepared for petrographic studies, representing pebble beds of the Benin Formation and Ajali Formation; from Mbiabong Ikon II (Location 1), Odoro Ikpe (Location 2), Ndot Ikpe (Location 3) and Atani Anoyom (Location 9). The samples were impregnated with epoxy resin and mounted on glass sides. They were trimmed and polished to the required thickness of 0.03mm, suitable for optical microscopy. Manual laboratory techniques were employed in the preparation thin sections of the pebbles. Each slide was labeled appropriately for petrographic study. The prepared slides were studied under plane – and cross-polarized light in order to identify the constituent minerals in addition, great care was taken in the procedure adopted because identification of the minerals and framework grains depend on the subtle characteristic interference colours (Curry et al., 1982). Photomicrographs of the thin sections were taken. The principle applied during the petrographic studies of the pebbles was to regard each pebble as an independent variable and interpretation was based on the data generated (Blatt, 1967).

Pebble Morphometry

Pebble morphometry involves direct measurements of individual particle axes (Briggs, 1977). The measurements and the computations that followed were used to interpret the environment of deposition of the pebble deposit. Eight hundred and fifty pebbles were morphometrically analyzed. The pebble beds in the study area were mostly unconsolidated and weakly cemented. For each bed that contained pebbles and sands after sieving, the pebbles were recovered for morphometric analysis and broken pebbles discarded. Orthogonal or principal axes (long, intermediate and short) of each pebble were measured using vernier calipers and the values recorded. The procedure adopted for measuring of the principal axes of each pebble, was to:

1. Place the pebble on a flat surface and measure the length of the intermediate axis (I) determined as the shortest possible visible diameter.
2. The length of long axis (L) is at right angle to the intermediate axis is next measured; rotating the pebble through 90° about that axes reveals the short axis.

From the data generated, the following parameters were determined, Maximum sphericity projection (MSP) after Sneed and Folk (1958), Oblate prolate index (OPI) after Dobkkins and Folk (1970), Disc rod index (DRI) and Flatness index or Flatness Ratio after Illenberger (1992). According to Tucker (1991), the ratios enumerated above are important in classifying the pebbles into four- end members (blade, discord, prolate and equant).

RESULTS AND DISCUSSION

Fieldwork

The lithostratigraphic sections of the study area are described in terms of their sedimentology from fieldwork, are presented below;

Location 1 Mbiabong Ikon II

Outcrop: 15.00m: 5°15.105'N, 7°45.390'E Strike: 42° NE/312°°SW Beds Dip: 2°-4° SW
Lithostratigraphic Unit: Benin Formation.
<u>Sedimentology</u>

The Benin Formation is the only lithostratigraphic unit encountered in Location 1 (Mbiabong Ikon II) is 15.00m thick. It comprises a sequence of pebble, sand and clay beds with thickness ranging from 0.10m to 3.70m. The bed boundaries are sharp to gradational. The pebble beds comprise medium to coarse–grained sandy pebbles and medium to coarse–grained pebbly sands, matrix supported made up of clays and sands. In addition, muscovite flakes were found within the clays that bound the pebbles. The color is Whitish to reddish, indicating intense weathering of feldspars with high iron content. The pebbles are rounded to very well-rounded indicating long distance of travel. This suggests that when the strong currents that deposited the pebbles waned, the matrix became deposited in the interstices of the pebbles. The medium to coarse grained sandy pebbles are clayey, lateritic, and reddish to brownish. The pebbles are sub-rounded to round in shape, poorly to very poorly sorted; in which large-scale foreset beds are conspicuous. The medium to coarse grained sandy beds, are clayey, poorly sorted to moderately well sorted, reddish to brownish and black. The clay beds are gray to black. Based on the sedimentological characteristics the environment of deposition fluvial (Braided stream)

Location 2 Odoro Ikpe

Outcrop: 62.00 m: Borehole (water well): 64.00 m: 5°30.000'N, 7°45.078' E

Strike for Nsukka Formation is 60° NE / 240° SW; strike for the Benin Formation is 32° NE / 212°SW: Dip of Nsukka Formation is 14° SW while the dip of Benin Formation is 4°SW

Lithostratigraphic Units: Nsukka and Benin Formations

<u>Sedimentology</u>

Two lithostratigraphic units were delineated on this outcrop and a borehole drilled 500m from the outcrop shows two units. The Nsukka Formation in this location is uncomformably overlain by the Benin Formation and an unconformity was established based on high dip values and biostratigraphy in addition, the borehole penetrated all the beds in the outcrop – Nsukka and Benin Formations. The Nsukka Formation is 4.92m comprising shale and limestone with thickness ranging from 0.91 m – 3.40 m and have sharp to gradational contacts. The shale is gray to greenish, massive and fractured in outcrop, in the borehole the shale is gray. Whereas the limestone, is whitish to brownish, and mainly composed of lime mud and sand fractions.

The Benin Formation is 53.73 m comprising a sequence of pebble, sand and clay beds ranging from 0.10 – 12.33 m. The bedding contacts are gradational to erosional with pebble lags. The Benin Formation in this location is friable, poor to very poorly sorted, angular to well-rounded, whitish to reddish sandstone with sedimentary structures such as planar cross beds. The pebble beds are, friable, round to very well rounded, poorly to very poorly sorted and matrix supported (comprising mainly clay, sand and silts), muscovite flakes are common especially in the clayey matrix. The sandy beds are fine to coarse grained sands – clay clasts are common and friable and poorly to very well- sorted. Iron stone fragments are common; in addition the sandy beds are whitish to brownish. The clayey beds have thicknesses, ranging from 0.10 – 0.90 m. They are whitish with reddish patches, mottled with bedding contacts being sharp to erosional.

Location 3 Ndot Ikpe

Outcrop: 16m: Strike: 76°, NE 276° SW: Beds dip: 6° SW

Lithostratigraphic unit: Benin Formation

<u>Sedimentology</u>

The Benin Formation is the only lithostratigraphic unit encountered in this location. It is 16 m thick, consisting of a sequence of clay, clayey medium to coarse grained pebbly sand, pebble conglomerate and fine to medium grained sands. The pebbly sand and sandy pebble beds are matrix supported, poorly to very poorly sorted with abundant muscovite flakes and clay intraclasts in addition toforeset beds whereas the sandy beds are moderately sorted and have cross bedding. Pebble shapes are sub – rounded to very rounded indicating long distance of travels. Based on colour two distinct pebble beds are delineated: reddish and a whitish to grayish bed. Bedding contact is gradational to sharp. Grain size analysis results points to a poorly sorted to very poorly sorted beds, negatively skewed and platykurtic. Grain size analysis results points to fluvial deposit (Braided stream) and based on lithostatigraphy, the Benin Formation did not extend beyond the OdoroIkpe area where it overlies the Nsukka Formation unconformably (Ideozu, 2014).

Stratigraphy of the Study Area

The stratigraphy of the study area is similar to the stratigraphy of the Afikpo Basin. It was synthesized from fieldwork, results of the biostratigraphic analyses and correlation of lithostratigraphic sections constructed from outcrops, borehole and hand dug wells and lithostratigraphic units identified include the Mamu, Ajali, Nsukka and Benin Formations. Imo Shale is absent from the stratigraphy of the study area, this may have been eroded or there was no deposition implying an unconformity. The sedimentary sequences comprise clays/shale, sand/sandstones, pebbly sand/conglomerates and limestone and make up the Mamu, Ajali, Nsukka and Benin Formations in the study area. This study reveals that the Nsukka and Mamu Formations (Cretaceous sediments) are overlain by the Benin Formation. There is lateral continuity of the Nsukka Formation from Arochukwu to Odoro Ikpe areas, based on field relations and biostratigraphic data (Figure 1).

Pebble Petrography Results

Eight hundred and fifty (850) pebbles were studied of which 10.0% or 85 pebbles were prepared for thin section studies (this represents pebbles sampled in the study area). In addition the remaining 90.0% were studied to determine whether they are quartz- or quartzite - pebbles. The results show that all the pebbles analysed are quartzite-pebbles - locations 1 (MbiabongIkon II), 2 (OdoroIkpe), 3 (Ndot Ikpe), 9 (Ugwuavo), and 8 (Utughugwu). The quartzite - pebbles were distinguished during field mapping, based on colour (reddish to brownish – after washing they are whitish), hardness, its weight and shape, quartzite - pebbles are usually well rounded (Blacker, 2013).

The results show that all the pebbles analyzed are quartzites based on the following observations:

1. Type of extinction: wavy (undulatory extinction)

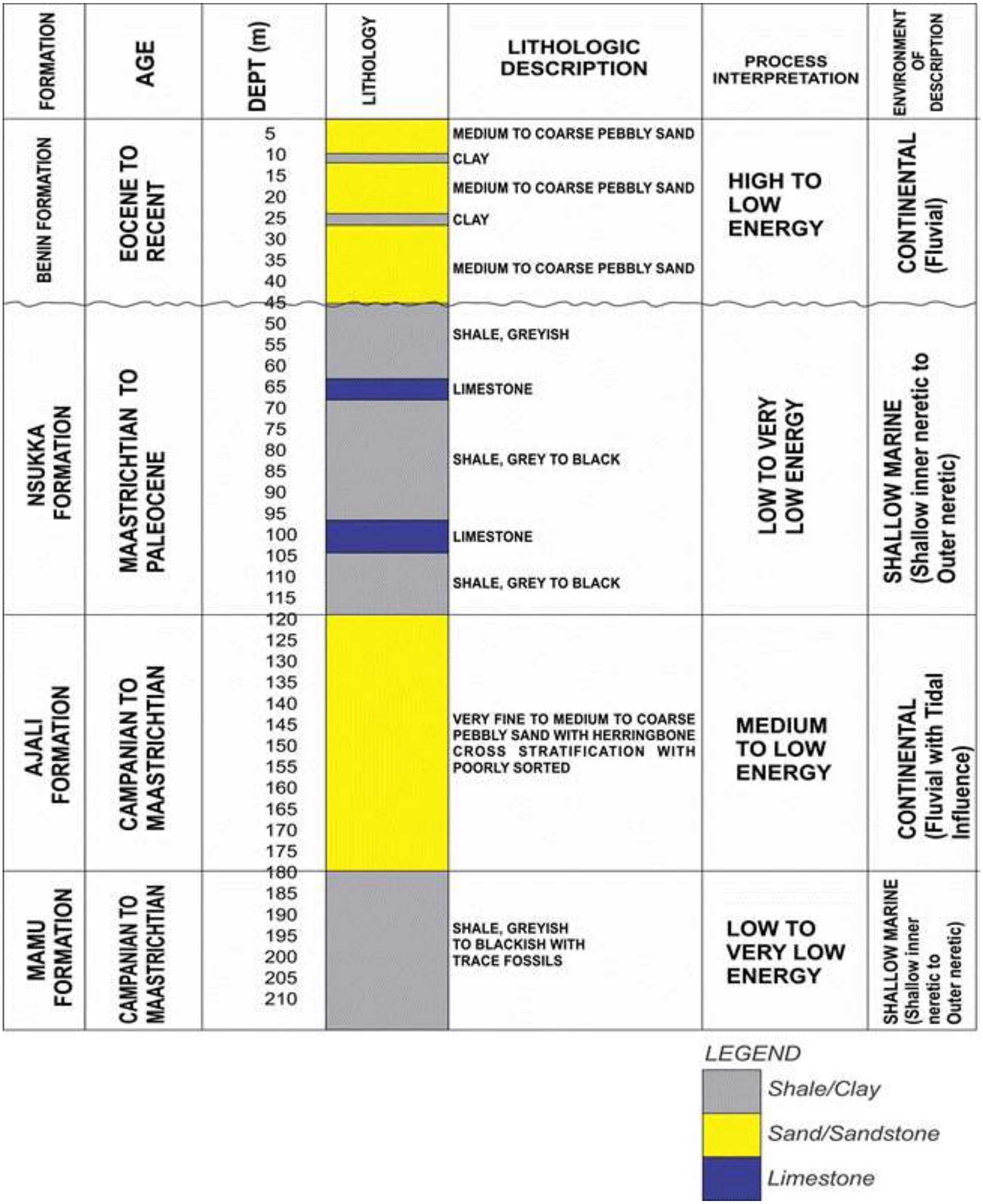


Figure1. Composite log of the study area showing lithostratigraphic units of the Study area based on correlation of lithologic logs and biostratigraphic data (Ideozu, 2014).

Plate1. Conglomeratic beds at Ndot Ikpe.
Insert - Inter - bedding of sandstone and paraconglomeratic beds at Ndot Ikpe (location 3)

2. Type of contacts: Sutured
3. Crystal shape: anheudral to subheudral aligned mainly in preferred orientations
4. Fractures are dominant, in preferred directions
5. The quartz are very mature quartz arenites (up to 100% quartz content)
6. The quartz grains in all the pebbles are polycrystalline.
7. Development of irregular grain boundaries with suturing and recrystallization at the grain boundaries.
8. Relic sedimentary beds were identified in some of the samples.

Interpretation

Optical evidence shows that the pebbles sampled from the study area are quartzites with the following: wavy or undulose extinction, stretched grains, relatively equant interlocking grains and development of foliation trend in preferred orientations (Sahay, 2013; Fisher, 2013). According to Mahmoud (2013), Blacker (2013) and Sharaf (2013) quartz grains from igneous origin are typically monocrystalline with unit extinction and no inclusions whereas polycrystalline quartz from a metamorphic origin typically possesses many crystals and is usually elongate with a preferred crystallographic orientation. Most quartzites have their origins from clean sandstones (arenites) that had been metamorphosed or deformed to such a degree that the quartz grains behave plastically at 250^0C or more. In thin sections (metamorphic– quartzites) the grains show undulatory extinction and has possibly developed foliation trend in preferred orientation of the c – axis whereas in thin sections of metamorphosed sandstones (quartzite) there is evidence of thedevelopment of pressure solution, undulatory extinction of the quartz grains and the development of irregular grain boundaries with suturing and recrystallization at grain boundaries (Fisher, 2013).

Analysis of thin sections of the pebbles showed that majority of the quartz grains which make up these pebbles have weakly foliated fabric, dominated by inequant grains randomly oriented while, some have preferred orientations. In addition, some exhibit ductile flow structures indicating that they may have been highly foliated schists. Ductile flow involves bending of the grains, crystallographically controlled plastic slip within grains and thermally activated recrystallization that change and reduce grain shape. Most of the pebbles have their quartz grains showing planar preferred orientations of inequant grains whereas some are fractured in preferred directions. The flow structures, mostly in preferred directions may have been the direction of invading fluid or the heat that deformed them by metamorphism (Myron, 1986).According to Hobbs et al., (1976) and Myron (1986), all metamorphic processes imprint new fabrics over old (inherited fabric such bedding, grain size and shape), sometimes obliterate them completely and the new fabrics (imposed fabric) now have new grain sizes and a parallel arrangement or preferred orientation of inequant grains. Thus the original inherited fabrics may be modified or completely obliterated by pervasive destructional or constructional metamorphic processes forming the imposed metamorphic fabric. Also a strongly foliated rock can be created from an initially isotropic one during ductile flow; in addition, existing layers in a rock may be transposed into a new one of different orientation during deformation (Plate 1).

Table1. Lithostratigraphic units in the Study Area modified after Oboh- Ikuenobe et al., (2005)

Period	Epoch	Afikpo Basin	Study Area
Tertiary	Pliocene-Recent	Benin Formation	Benin Formation
	Miocene-Mid Eocene	Ogwashi-Asaba Formation	
	Mid-Upper Eocene	Ameki/Bende Sandstone	
	Paleocene	Imo Shale Nsukka Formation	Nsukka Formation
Cretaceous	Maastrichtian Campanian	Ajali Formation	Ajali Formation
		Mamu Formation	Mamu Formation
		Nkporo Shale/Afikpo Sandstone	Nkporo Shale
		Enugu/Owelli Formation Agwu Formation	Enugu/Owelli Formation Agwu Formation
	Santonian Coniacian	Agbani Sandstone Eze-Aku Formation Odukpani Formation	Agbani Sandstone Eze-Aku Formation Odukpani Formation
	Turonian Cenomanian		
	Albian	Asu River Group	Asu River Group

The deformation of rocks results from the internal adjustments within the mineral grains notably by gliding and dislocation (Billings, 1972). Low grade metamorphic rocks tend to be better foliated because of the greater amounts of platy phyllosilicates compared to high grade rocks (Ekwueme, 2003). The absence of schists, mica and muscovites in all the pebbles analyzed in thin sections, show that the quartz grains had been metamorphosed to quartzites and are not of igneous origin as espoused by Amajor (1986). For example, the interlayer boundaries of quartzites and schists metamorphosed under the same pressure – temperature conditions display conspicuous different developments of foliation. The schists may be strongly foliated because of high degree of preferred orientation of abundant mica or muscovite flakes, whereas quartzites are only weakly foliated because they are made up of discoidal grains. In metamorphosed sandstone (quartzite), relict epiclastic fabric may be quite conspicuous even where deformation of the body has occurred, relict bedding is commonly inherited in low grade metamorphosed sediments because layers of contrasting mineralogic composition and fabric apparently develop during metamorphism (Myron, 1986).The geometry of the imposed metamorphic fabric reflects the pattern of cohesive deformational flow or lack of flow during the metamorphic event and indirectly the nature of the stress applied to the rock body whether it is hydrostatic or non-hydrostatic stress (Billings, 1972). From the petrographic studies, 100% of the pebbles analyzed suggest that they are quartzites indicating that they have a common origin (See Plates below) and the source area maybe the surrounding Basement Complex Rocks in the vicinity of the study area. The fabric of the quartzites as seen in thin section studied may be the result of recrystallization as a result of increase in temperature by contact with the magmatic intrusion (contact metamorphism), this may have led to adjustment of boundaries of grains present uncomplicated by chemical reaction because quartz is a stable mineral under most magmatic conditions. Quartz grains may be made unstable because of high strain impacted by deformation to minimize the strain, unstrained larger grains will form and this may account for the larger euhedral inequant grains in most of the samples (Hobbs et al., 1976). All anisotropic fabric elements in regional bodies especially preferred mineral grain orientations, planar and linear fabrics such as folds commonly display a unity in geometry and may be explained as resulting from deformation and crystal growth in the solid state and by synchronous ductile flow and crystal growth under non hydrostatic stress (Hobbs et al., 1976).

Morphometric Analysis Results

Pebble morphometric analysis was carried out through direct measurements of the long, intermediate and short axes for eight hundred and fifty (850) samples collected from studied outcrops, at specific beds of Locations 1, 2, 3, 7, 8, 9 and 18. Using appropriate formula, computation was done for the following parameters of flatness ratio, maximum projection sphericity, disc rod ratio, as well as oblate prolate index (Dobkkins and Folk, 1970). The pebble shape was classified using Sneed and Folk’s 1958 scheme and pebble shape for each sample was determined using the appropriate formula (Dobkkins and Folk, 1970). A summary of the results are presented in Table 1.

Interpretation

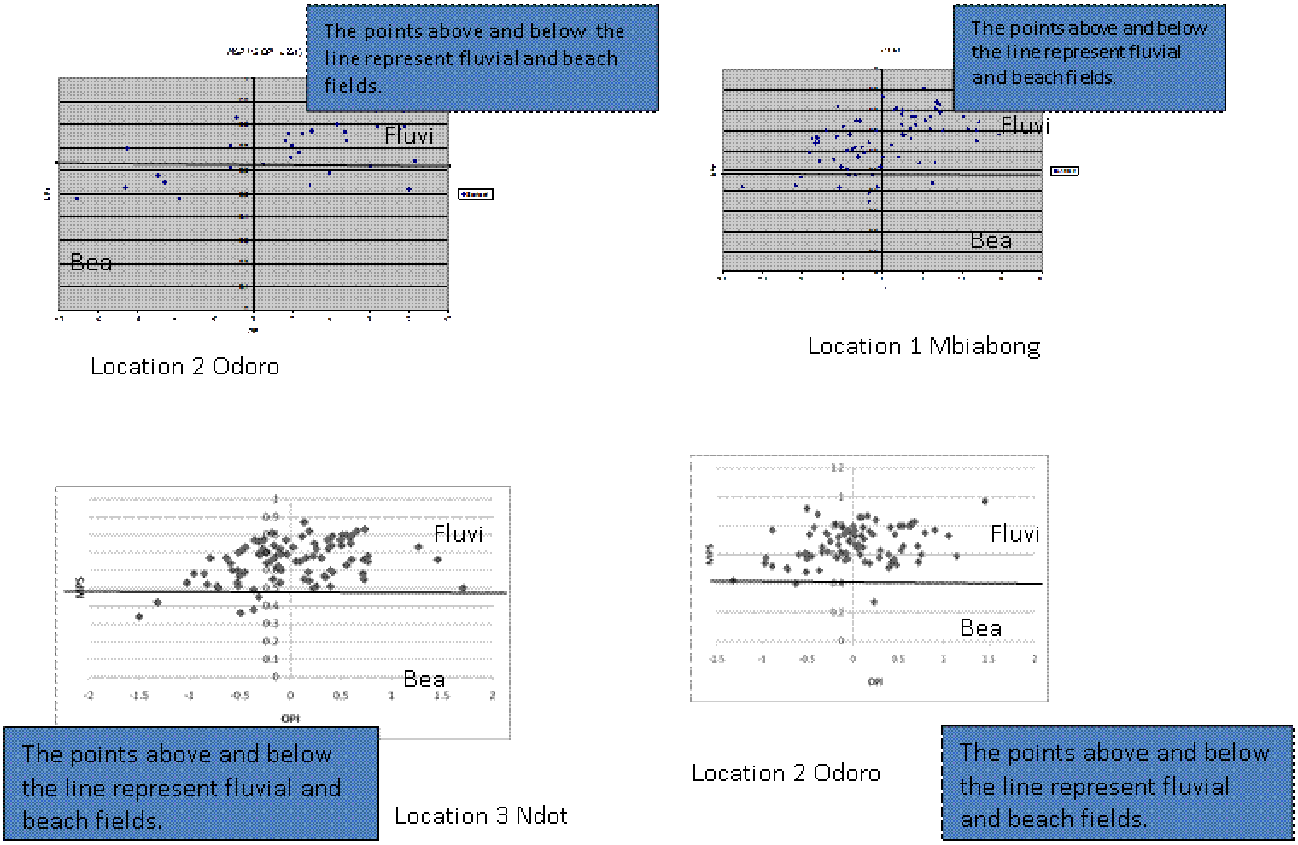
Dobkkins and Folk (1970), Folk (1974), Humbert (1968) and Sneed and Folk (1958) in their works suggest that shape attributes and other parameters should classify a pebble into a distinct environment. The following formed the basis for classification of the pebbles in the study area as either beach or fluvial based on their works.

1. Pebbles of fluvial origin have lowest roundness, high sphericity and almost neutral OPI values. These values are uniform from one river to the next and all pebbles measured may have similar sizes.
2. High energy beach pebbles have highest roundness, low sphericity and are distinctly oblate. There is a wide variation in shape from one pebble size to the next in any one beach and from one beach to another.
3. Low energy beaches have intermediate roundness, sphericity ranges from extremely low on sandy beaches.
4. Small pebbles tend to be oblate while large pebbles are prolate. On sandy low energy beaches with waves under 15 feet, the smallest pebbles are almost discoidal.

For environmental discrimination of pebble suites, sphericity values under 0.625 and OPI of more than –1.50 identify beach pebbles. In addition, with prolonged transport, roundness increases in both beach and fluvial environments so that pebbles from both environments may have indistinguishable roundness values. Sphericity on the contrary tends to decrease with intense beach abrasion whereas it remains fairly constant or increase slightly with fluvial transport. The results of the long, intermediate and short axes of the pebbles measured showed that average pebble size ranges from -2.6 to -4.4 Phi with average -3.5 Phi. Based on the average size (-3.5 Phi) the depositing medium is very competent. The modes of transport of these pebbles are mainly by saltation and rolling, and abrading process may have contributed to the eventual and final shape of the pebbles. These pebbles may have been unroofed as a result of weathering in which the paleoclimate at the time these clasts were unroofed may have played a prominent role. The Maastrichtian climate was humid, and may have accounted for intense weathering of the Basement Complex Rocks within the vicinity of the study area. The geometric forms which describe 3-D aspect of a pebble are based on ten classes established by Sneed and Folk (1958) for pebble classification. These include compact, compact bladed, compact platy, compact elongate, bladed, platy, elongate, very bladed, very platy and very elongate The diagnostic forms for pebbles of river (fluvial) origin are compact, compact bladed, compact platy, compact elongate, whereas diagnostic forms for pebbles of beach origin are very bladed, very platy bladed and platy. The results show that 61.4% of the samples comprise river forms while 38.6% of the samples comprise beach forms. This result is consistent with the scatter plot of maximum projection sphericity vs oblate prolate index which shows that majority of the pebbles plot within the fluvial field. Considering the mean geometric forms deduced from the plot on the shape measurement triangle most of the samples plotted in the blade field which are characteristic of pebbles of fluvial origin (Sneed and Folk, 1958). Pebble morphometric result shows that mean maximum sphericity projection (MSP), oblate-prolate (Index OPI), disc-rod-index (DRI), flatness ratio (FR) and mean clast size is 0.623, 0.396, 0.517, 0.443 and 14.47mm while the range of values are 0.35 – 0.92, 11.30 to –14.30, 0.03 – 0.99, 0.20 – 0.85 and 1.0 to -5.4 phi respectively. According to Dobkkins and Folk (1970), Humbert (1968), Sneed and Folk (1958) and Illenberger and Reddering (1993), the maximum projection sphericity of pebbles are generally high for fluvial than for beach origin. Beach pebbles usually show lower maximum projection sphericity of less than 0.40 whereas fluvial pebbles usually show a higher maximum projection sphericity of more than 0.40. The 0.65/0.66 line separates beach from fluvial pebbles (Dobkkins and Folk, 1970). The results show that 53.8% of the samples plot above the 0.65/0.66 line separating fluvial from beach pebbles whereas 46.2% plot below this line. The bladed pebble shape are characteristic of fluvial environments (Dobkkins and Folk, 1970); this is consistent with the interpretation of the pebble shapes (about 60 % of the pebbles analyzed) and grain size analysis data that suggests a fluvial environment for the pebble belt in the study area (Ideozu, 2014).

DISCUSSION

The results of the pebble morphometry (this work), is in agreement with the works of Asukwo et al (2015), Inyang (2001), Inyang and Enang (2001) who did a similar work in the study area and Ikoro (2014) in Uwakanda . Based on bivariate plots and applying the principles and conclusions reached by Dobkkins and Folk (1970), Humbert (1968) and Sneed and Folk (1958) who used bivariate plots of MSP versus OPI to discriminate between fluvial - deposited pebbles and beach - deposited pebbles the environment of deposition is interpreted as fluvial. In addition grain size analysis results and interpretation supports a fluvial origin for the associated sands/sandstone and pebbly sands in the study area (Ideozu, 2014). Considering the size of the pebbles (-3.5phi), only a very competent fluvial means with high velocity and high erosive power would deposit such pebbles. This may account for the unconformity identified between the Benin Formations (Tertiary) and Nsukka Formation (Cretaceous).Petrographic analysis of the pebbles in the study area, shows that the pebbles



The points above and below the line represent fluvial and beach fields.

Location 2 Odoro

The points above and below the line represent fluvial and beach fields.

Location 1 Mbiabong

The points above and below the line represent fluvial and beach fields.

Location 3 Ndot

Location 2 Odoro

The points above and below the line represent fluvial and beach fields.

Figure2. Scatter Plots of MSP vs OPI Representing Samples from the Study Area (After Sneed and Folk, 1958).

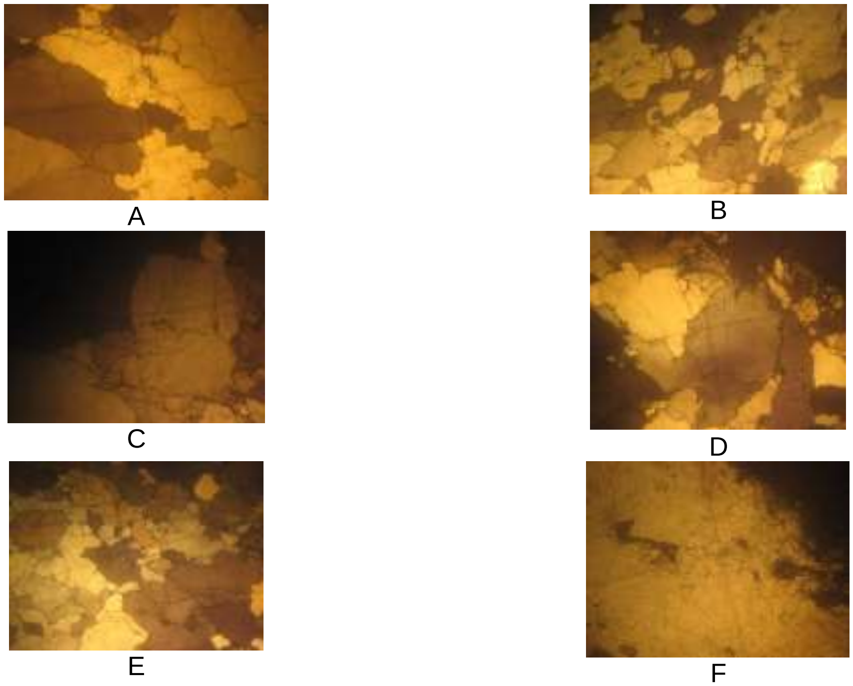


Plate 1.1. Photomicrographs of some of pebbles encountered in the study area. (Magnification X10).A – F The pebbles have polycrystalline quartz grains, quartz grains exhibit development of irregular grain boundaries with suturing, undulatory extinctions charasteristic of quartzites and and are morphologically elongated (flattened) evidence of streched quartz grain. A. Possibly developed foliation trend in preferred orientation of the c-axis (Fisher, 2013), B. Pebble grain showing relic sedimentary structure – bedding (laminar) based on differences in grain size, undulatory extinctions charasteristic of quartzites and are morphologically elongated (flattened), sutured intercrystalline boundaries. F The quartz grains observed show undulatory extinction with inclusion of pyrite.

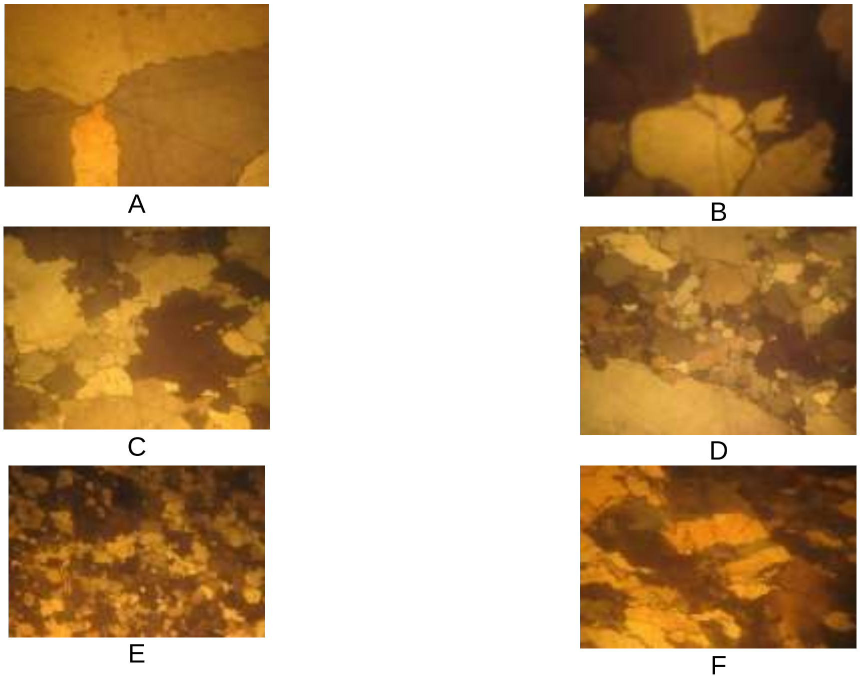


Plate 1.2. Photomicrographs of some of pebbles encountered in the study area. (Magnification X10). A – F. The pebbles have polycrystalline quartz grains, quartz grains exhibit development of irregular grain boundaries with suturing, undulatory extinctions charasteristic of quartzites and and are morphologically elongated (flattened) evidence of strecthed quartz grain. Evidence of relatively inequant interlocking grains common in metamorphic quartz (Sahay, 2013) and possibly developed foliation trend in preferred orientation of the c-axis (Fisher, 2013), D - E Pebble grain showing relic sedimentary structure – bedding based on differences in grain size, undulatory extinctions charasteristic of quartzites and are morphologically elongated (flattened), sutured intercrystalline boundaries and evidence of relatively equant intelocking grains common in metamorphic quartz (Sahay, 2013).

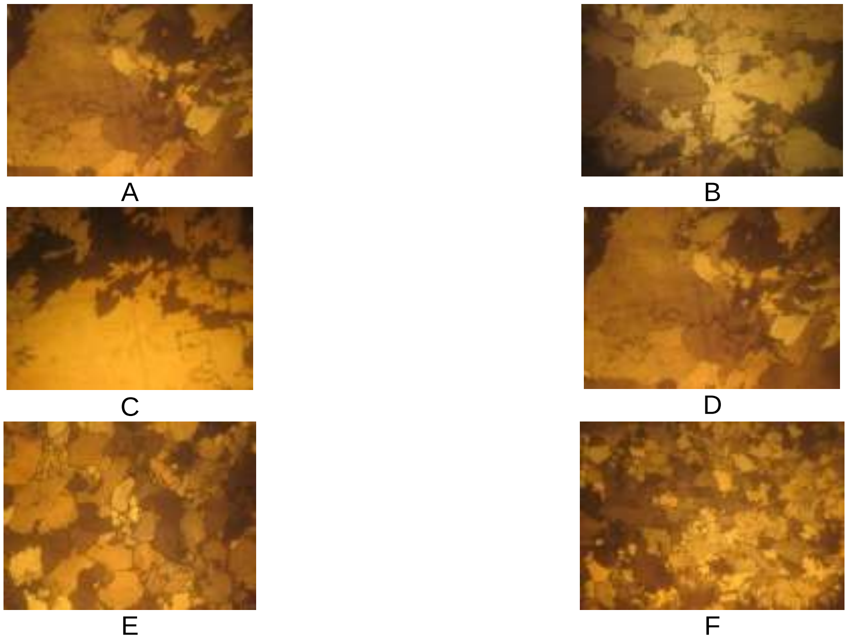


Plate 1.3. Photomicrographs of some of pebbles encountered in the study area. (Magnification X10). A– F The pebbles have polycrystalline quartz grains, quartz grains exhibit development of irregular grain boundaries with suturing, undulatory extinctions charasteristic of quartzites and and are morphologically elongated (flattened) evidence of strecthed quartz grain. Evidence of relatively inequant interlocking grains common in metamorphic quartz (Sahay, 2013) and possibly developed foliation trend in preferred orientation of the c-axis (Fisher, 2013). A -D Evidence of pyrite in the samples E - F Pebble grain showing relic sedimentary structure – bedding based on differences in grain size, undulatory extinctions charasteristic of quartzites and are morphologically elongated (flattened), sutured intercrystalline boundaries and evidence of relatively equant intelocking grains common in metamorphic quartz (Sahay, 2013).

1
L = 3.00cm
I = 3.00cm
S = 0.50cm
Pebble shape = VP

2
L = 5.00cm
I = 3.00cm
S = 2.50cm
Pebble shape = CB

3
L = 5.00cm
I = 2.00cm
S = 1.80cm
Pebble shape = E

4
L = 5.90cm
I = 3.20cm
S = 1.50cm
Pebble shape = VB

5
L = 4.20cm
I = 2.50cm
S = 1.30cm
Pebble shape = B

6
L = 4.10cm
I = 3.00cm
S = 0.91cm
Pebble shape = VP

7
L = 2.50cm
I = 2.20cm
S = 0.50cm
Pebble shape = VP

8
L = 4.10cm
I = 2.20cm
S = 3.00cm
Pebble shape = C

Plates 1.4. Some representative Pebbles Sampled from the Study Area. (L = Long axis, I = Intermediate axis, S = Short axis, VP = Very Platy, CB =Compact Bladed, VB = Very Bladed, B = Bladed, E = Elongate and C = Compact

Table2. Summary of Maximum Projection Sphericity (MPS)

LOCATION	Depth (m)	MEAN	RANGE
L1S2	0.4	0.66	0.4 -0.91
L1S3	1.8	0.65	0.35 - 0.91
L1S5	2.4	0.63	0.4 -0.95
L2S7	0.61	0.64	0.24 -0.90
L2S8	1.52	0.69	0.48 - 0.90
L2S19	0.42	0.65	0.27 - 0.91
L2S21	0.7	0.62	0.38 - 0.88
L2S25	0.3	0.63	0.37 - 0.89
L3S2	0.59	0.58	0.47 - 0.92
L3S4	2.25	0.58	0.26 - 0.87
L3S5	1.22	0.66	0.47- 0.90
L3S8	2.6	0.65	0.4 -0.91
L3S9	0.76	0.65	0.42 - 0.90
L8S1		0.66	0.24 – 0.97
L9S1		0.65	0.32 – 0.87

Table3. Summary of Flatness Ratio (FR)

LOCATION	DEPTH(m)	MEAN	RANGE
L1S2	0.4	0.46	0.23 - 0.87
L1S3	1.8	0.45	0.16 - 0.72
L1S5	2.4	0.46	0.22 - 0.92
L2S7	0.61	0.43	0.23 - 0.75
L2S8	1.52	0.48	0.26 - 0.75
L2S19	0.42	0.47	0.24 - 0.86
L2S21	0.70	0.40	0.18 - 0.71
L2S25	0.30	0.42	0.20 - 0.81
L3S2	0.59	0.39	0.24 - 0.88
L3S4	2.25	0.39	0.12 - 0.86
L3S5	1.22	0.46	0.26 - 0.95
L3S8	2.60	0.44	0.21 - 0.78
L3S9	0.76	0.47	0.22 - 0.78
L8S1		0.48	0.29 – 0.74
L9S1		0.45	0.18 – 0.78

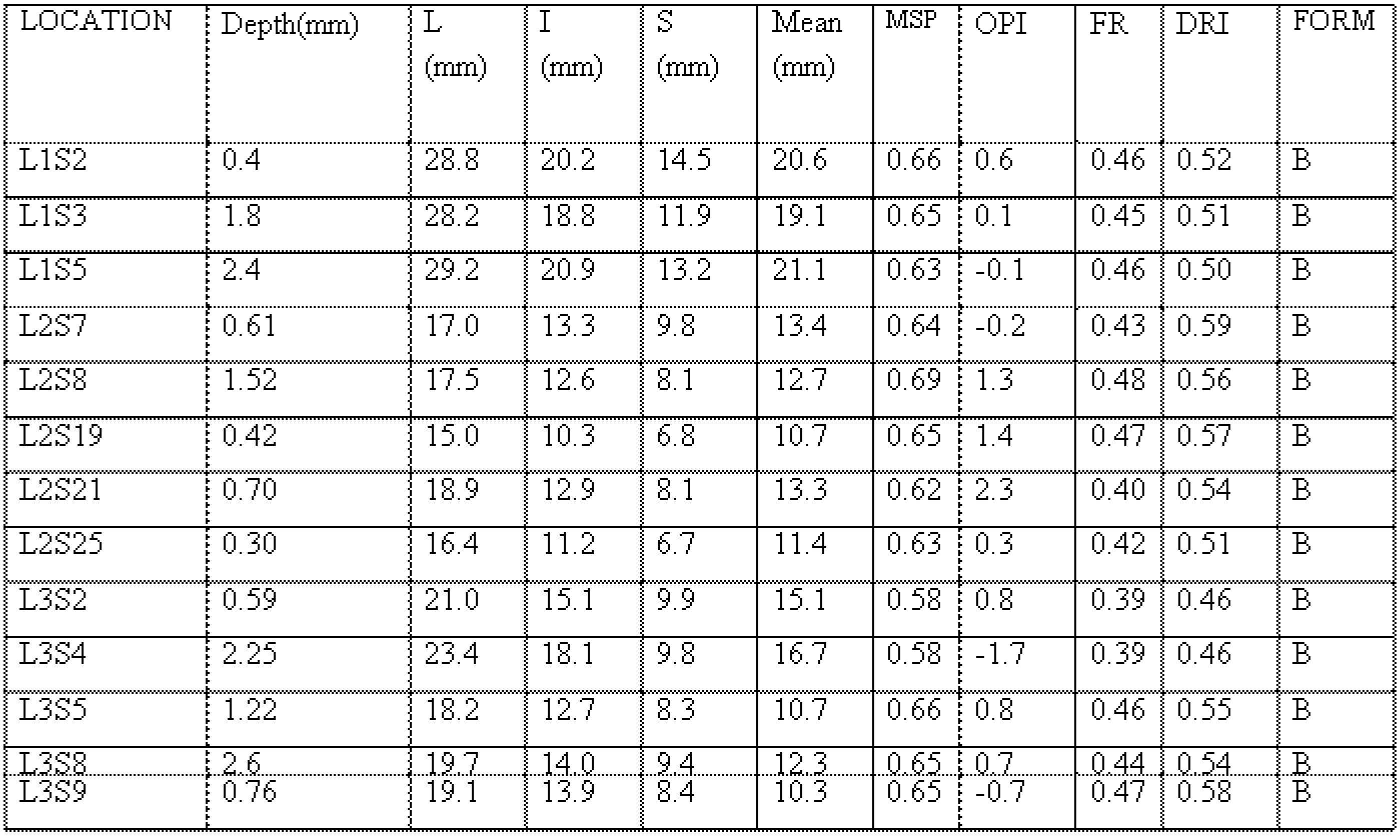
Table4. Summary of Oblate – Prolate Index (OPI)

LOCATION	DEPTH(m)	MEAN	RANGE
L1S2	0.4	0.64	-11.9 to 13.7
L1S3	1.8	0.14	-14.6 to 17.5
L1S5	2.4	-0.14	-14.2 to 11.8
L2S7	0.61	-0.16	-9.6 to 7.0
L2S8	1.52	1.32	-8.3 to 9.1
L2S19	0.42	1.36	-9.5 to 0.00
L2S21	0.7	2.29	-13.4 to 12.0
L2S25	0.3	0.25	-15.6 to 18.9
L3S2	0.59	0.76	-15.7 to 12.5
L3S4	2.25	-1.71	-13.4 to 14.5
L3S5	1.22	0.75	-14.2 to 10.3
L3S8	2.6	0.70	-14.6 to 12.3
L3S9	0.76	-0.60	-12.0 to 16.7
L8S1		0.05	- 0.97 to 1.45
L9S1		-0.007	- 1.32 to 1.70

Table5. Summary of Mean Clast Size

LOCATION	DEPTH(m)	MEAN(mm)	RANGE(mm)
L1S2	0.4	20.60	12.98 - 38.29
L1S3	1.8	19.36	12.16 - 37.56
L1S5	2.4	21.04	10.87 - 35.83
L2S7	0.61	8.56	4.76 - 16.66
L2S8	1.52	13.09	4.77 - 25.83
L2S19	0.42	10.67	7.22 - 16.05
L2S21	0.7	12.15	6.89 - 17.56
L2S25	0.3	11.39	6.53 - 20.37
L3S2	0.59	13.87	4.96 - 32.85
L3S4	2.25	12.45	6.01 - 32.3
L3S5	1.22	10.74	4.33 - 19.85
L3S8	2.6	12.25	5.88 - 29.3
L3S9	0.76	10.29	6.04 - 19.66
L8S1		27.67	14.07 – 49.81
L9S1		21.44	11.43 – 36.01

Table6. Summary of Parameters Analyzed for the Study Area



LOCATION	Depth(mm)	L (mm)	I (mm)	S (mm)	Mean (mm)	MSP	OPI	FR	DRI	FORM
L1S2	0.4	28.8	20.2	14.5	20.6	0.66	0.6	0.46	0.52	B
L1S3	1.8	28.2	18.8	11.9	19.1	0.65	0.1	0.45	0.51	B
L1S5	2.4	29.2	20.9	13.2	21.1	0.63	-0.1	0.46	0.50	B
L2S7	0.61	17.0	13.3	9.8	13.4	0.64	-0.2	0.43	0.59	B
L2S8	1.52	17.5	12.6	8.1	12.7	0.69	1.3	0.48	0.56	B
L2S19	0.42	15.0	10.3	6.8	10.7	0.65	1.4	0.47	0.57	B
L2S21	0.70	18.9	12.9	8.1	13.3	0.62	2.3	0.40	0.54	B
L2S25	0.30	16.4	11.2	6.7	11.4	0.63	0.3	0.42	0.51	B
L3S2	0.59	21.0	15.1	9.9	15.1	0.58	0.8	0.39	0.46	B
L3S4	2.25	23.4	18.1	9.8	16.7	0.58	-1.7	0.39	0.46	B
L3S5	1.22	18.2	12.7	8.3	10.7	0.66	0.8	0.46	0.55	B
L3S8	2.6	19.7	14.0	9.4	12.3	0.65	0.7	0.44	0.54	B
L3S9	0.76	19.1	13.9	8.4	10.3	0.65	-0.7	0.47	0.58	B

analyzed from both the Ajali Formation and the Benin Formation are quartzite-pebbles and were probably derived from the same source which is believed to be the southeastern Basement Complex Rocks (Obudu Plateau and Oban Massif). This work settles the origin and composition of the pebbles found in the Benin and Ajali Formations for the first time using petrographic analyses, complimented by morphometric and grain size analysis (figure 2 above).

SUMMARY AND CONCLUSION

Petrographic and morphometric analyses used in this study settle the controversies surrounding the origin and depositional environment of the conglomeratic beds by many workers in the study area. The environment of deposition of the pebble belt is interpreted as fluvial whereas the origin of the pebbles from petrographic evidence is metamorphic quartzites unroofed from the Oban Massif, Southeastern Nigeria.

REFERENCES

Amajor LC (1986). Sedimentary Facies Analysis of the Campano-Maastrichtian Ajali Formation. SE Nigeria. Bulletin of Nigeria Mining and Geoscience Society 21:171-176.

Asukwo EI, Inyang DO, Ikoro DO (2015). Pebble Morphormetric Analysis of Awi Formation in Calabar Flank, Nigeria. J. Edu. Res. Technol. 4(4):93-110.

Avbovbo AA (1978). Tertiary Lithostratigraphy of the Niger Delta. American Association of Petroleum Geologist Bulletin 62: 295 – 300.

Benkhelil J (1986). Cretaceous Deformation, Magmatism and Metamorphism in the Lower Benue Trough. Nig. Geol. J. 22: 467 – 493.

Benkhelil J (1987). The Origin and Evolution of Cretaceous Benue Trough. J. Afr. Earth Sci. 8(1): 251 – 282.

Billings MP (1972). Structural Geology, 3rd Edition. Pp 1 – 172.

Burke KC, Dessauvagie TFJ, Whiteman AJ (1971). The Opening of the Gulf of Guinea and the Geological History of Benue Depression and Niger Delta. Nature Physical Science 233(38): 51 – 55.

Carter JD, Barber W, Tait EA (1963). The Geology of Parts of Adamawa, Bauchi and Bornu Provinces in Northeastern Nigeria. Geological Survey of Nigeria. Bulletin Number 30: 24.

Chikani SN, Ohia IA, Egbu OC (2010). Paleo-environmental and Structural Evolution of Clastic Sediments in Parts of Afikpo Syncline (Southeastern Nigeria). NMGS Book of Abstracts, Pp 30.

Chukwu-Ike IM (1978). Interpretation of Marginal En-echelon Lineaments in the Mid Benue Trough, Nigeria. Nig. J. Min. Geol. 15(1): 14 - 18.

Dobkkins JE, Folk RL (1970). Shape Development in Tahiti-Nui. J. Sedimentary Petrol. 40: 1167- 12033.

Ekwueme BN (2003). The Precambrian Geology and Evolution of Southeastern Nigerian Basement Complex. Publishers University of Calabar Press. Pp 1 – 131.

Ekwueme BN, Nyong EE, Petters SW (1995). Geological Excursion Guidebook to Oban Massif, Calabar Flank and Mamfe Embayment. SE Nigeria 31st An'nual Conference of Nigeria Mining Geoscience Scociety. Pp. 1-36.

Hamblim WK (1958). Cambrian Sandstones of Northern Michigan: Michigan Geological Survey Publication; 51:149.

Hobbs BE, Means WD and Willians PF (1976). An Outline of Structural Geology. New York, Wiley and Sons. Pp 252 – 264.

Hoque M, Nwajide CS (1984). Tectono – Sedimentological Evolution of an Elongate Intrcratonic Basin (Aulacogen). The Case of the Benue Trough of Nigeria. J. Min. and Geol. 21: 19 – 26.

Humbert FL (1968). Selection of Wear and of Pebbles on Gravel Beaches. University of Groningen, Geological Instute Publiction. 190: 144.

Ideozu RU (2014). Sedimentology of Post Santonian Sediments in Parts of Afikpo Basin Southeastern Nigeria Unpublished Ph.D Thesis, Geology Department, University of Port Harcourt.

Ikoro DO (2014). Depositional Environment of the Exposures of Turonian Eze-Aku Formation at Uwakanda 1, Southeastern Nigeria. Int. Res. J. Geol. and Min. 4(6):143-153

Illenberger WK (1992). Pebble Shape (and Size) – Reply: J. Sed. Petrol. 62: 538 – 542.

Illenberger WK, Reddering JSV (1993). An Evaluation of Shape Indices as Paleoenvironmental Indicators Using Quartzite and Metavolcanic Clasts in Upper Cretaceous to Paleogene Beach River and Submarine Fan Conglomerates. Sedimentology, 40:1019 – 1021.

Inyang DO (2001). Lithofacies Analysis of Conglomerate in the Northeastern Part of the Niger Delta, Nigeria. Global J. Pure and Applied Sci. 7(3):493-499.

Inyang DO, Enang EI (2002). Use of Statistical Parameters in the Sedimentological Study of Conglomerates in part of Niger Delta, J. Min. Geol. 38: 21-26.

Inyang DO (2010). Alluvial Stratigraphy and Provenance of Sandstone – Conglomerate Deposits in the Northeastern Sector of the Niger Delta, Nigeria. Unpubl. Ph.D Thesis, Department of Geology, University of Port Harcourt. Pp 1-46.

Kogbe CA (1976). The Upper Cretaceous Abeokuta Formation of South Western, Nigeria. Nigeria Field No. 4, December 1974.

Luttig G (1962): The Shape of Pebbles in Continental Fluviatile and Marine Facies. International Association of Hydrology. 23: 253 – 258.

Moss AJ (1962). Physical Nature of Common Sandy and Pebbly Deposits. Part I, Am. J. Sci. 260: 337 – 373.

Murat RC (1970). Stratigraphy and Paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In Dessauvagie - TFJ. and Whiteman AJ. (ed.) African Geology University of Ibadan Press. Pp. 251-266.

Murat RC (1972). Stratigraphy Cretaceous and Lower Tertiary in Southern Nigeria: In Dessauvagie - TFJ and Whiteman AJ (ed.) African Geol. University of Ibadan Press. Pp. 251-266.

Numberg D, Muller RD (1991). The Tectonic Evolution of the South Atlantic from Late Jurassic to Present.Tectonophysics. 131: 27 – 53.

Nwajide CS (1990). Cretaceous Sediments and Paleogeography of Central Benue Trough. In: Ofoegbu, C. O (ed). The Benue Trough, Structural Evolution. Friedr. Vieweg and Sohn, Brauchweig/Wiesbaden. Pp. 19 – 38.

Oboh–Ikuenobe FE, Chuks GO, Jaramilo CA (2005). Lithostratigraphic Units of Anambra basin. Correlation Chart Cretaceous Tertiary Strata in Southern Nigeria. J. Afr. Earth Sci. 41:101-112.

Odeyemi IB (1979). Orogenic Events in the Precambrian Basement of Nigeria. West African Newsletter. Number 3, IGCP 108/144, Pp. 18 – 23, Abidjan, Ivory Coast.

Ofodile ME (1976). The Geology of Middle Benue Nigeria, Cretaceous Res. 1: 101 – 124.

Orubima II (2009). Heavy Mineral Studies of Sandstones and Clast Petrography of Conglomerates in Parts of Ini L.G.A AkwaIbom State South – East Nigeria. Unpublished B.Sc. Thesis University of Port Harcourt. Pp. 1 – 32.

Oyawoye MO (1964). The Geology of Nigerian Basement Complex – A Survey of our Present Knowledge of them. J.f Nig. Min. Geol. 1(2): 87 – 108.

Petters SW (1989). AkwaIbom State: Physical Background, Soils, Land Use, and Geological Problems. Technical Report of the Task Force on Soils and Land Use Survey. AkwaIbom State Government Printers, Uyo.

Popoff M (1990). Deformation IntracontinentaleGondwanienne Rifting Mesozoique en Afrique (Evolution Meso – Cenozoique du Fosse` de la Benoue, Nigeria). Relations avec l' Ocean AtlantiqueSud. The`se d' Etat, Universite Aix – Marseille III Pp. 425.

Popoff M, Raillard S, Mascle J, Auroux C, Basile C, Equamarge Group II (1989). Analyse d' un Segment de la Marge Transformante du Ghana: Resultats de la CampagneEquamarge II (Mars, 1988). Camples Randus Hebdomedeires des Siaces du Academes des Sci. 2: (309) 481 – 487.

Popoff M, Wiedmann J, De-Klasz I (1986). The Cretaceous Gongila and Pindiga Formations, Northeastern Nigeria: Subdivisions, Age, Stratigraphic Correlations and Paleogeographic Implications. Eclogae Geological Helv. 9(2):343-363.

Rahaman MA (1988a). Recent Advances in the Study of the Basement Complex of Nigeria. In: P. O. Oluyide (Co – ordinator), Precambrian Geology of Nigeria. Geological Survey of Nigeria Publication. Pp. 11 – 43.

Reyment R A (1965). Aspects of geology of Nigeria. University of Ibadan Press. Nigeria.

Short KC, Stauble AJ (1967). Outline of the Geology of Niger Delta. Ame. Ass. Pet. Geol. Bulletin 51(5):761–779.

Simpson S (1954). The Nigerian Coal Field. The Geology of parts of Onitsha, Owerri, and Benue Provinces, Geological Survey of Nigeria, Bulletin 24.

Sneed ED, Folk RL (1958). Pebbles in the Lower Colorado River, Texas: A case Study in Particle Morphogenesis. J. Geol. 66:114-150.

Udo IG (2004). Sedimentology of Conglomerate and Pebbly Sandstone Beds in Akwa Ibom State. Unpublished M. Sc Thesis, Department of Geology, University of Port Harcourt. Pp. 1-99.

Ukaegbu VU, Akpabio IO (2009). Geology and Stratigraphy of Middle Cretaceous Sequences Northeast of Afikpo Basin Lower Benue Trough, Nigeria. Pacific J. Sci.Technol. 10(1): 1-10.

How to cite this article: Ideozu and Ikoro. Sedimentology of Conglomeratic Beds within Odoro Ikpe – Arochukwu Axis: Afikpo Basin Southeastern Nigeria. Int. Res. J. Geol. Min. 5(3):30-45