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Petrography and provenance analysis of conglomeritic lithofacies of the Ameki Formation in the northeastern part of the Niger Delta Basin, Nigeria.

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---***ABSTRACT***---

The integration of sedimentary petrography, paleocurrent and heavy mineral analyses of the conglomeritic lithofacies of the Ameki Formation in the northeastern part of the Niger Delta Basin was donein order to determine the provenance, tectonic and paleoclimatic setting. The sandstone has more than 95% quartz and it is quartz arenite.Petrographic analysis shows the preponderance of monocrystalline nonundulose quartz and absence of inclusions suggesting a volcanic igneous source terrain. The absence of feldspar suggests that the detritus was derived under a hot and humid palaeoclimate. The abundance of euhedral zircon and pink euhedral tourmaline suggest that the sediment was derived from an igneous source terrain. However, the paucity of kyanite and sillimanite indicate a minor contribution from a metamorphic source. Analysis of cross-beds data gives a unimodal paleocurrent patterntrending southwest which indicates that the provenance is northeast.The mineral composition of the sand considered in conjunction withpaleocurrent direction points to the northeastern granitic basement complex rocks of the Cameroon Massif.

Key words: *Provenance, petrography, conglomeritic lithofacies, Niger Delta, paleoclimate,*

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I. INTRODUCTION

The reconstruction of the origin of sediments or provenance is very important in understanding the relationship between a sedimentary deposits and the source area. Provenance study can also provide clues to the relief and climate of the source area, the tectonic setting, the transport history and the diagenetic modifications of sediments (Pettijohn et al., 1987). The compositional and textural features of sandstone and paleocurrent analysis provide the evidence for deducing the provenance information (Pettijohn et al., 1987). Sandstone provenance may be identified by petrographic study of the undulosity and polycrystallinity of quartz grains (Basu et al., 1975), types of feldspar present (Pittman, 1970), and rock fragments (Pettijohn et al., 1987). Grain roundness and degree of feldspar alteration may give clues to the transport history, relief and climate of the source area (Folk, 1980). The tectonic setting can be determined by the relative proportion of quartz, feldspar and rock fragments (Dickinson, 1985). Because diagenetic processes can cause considerable post-depositional modification of the original mineralogical composition of a sandstone, effort should be made to identify altered and replaced mineral grains (McBride, 1985, 1987). Heavy mineral analysis is an effective tool for reconstruction of sediment provenance (Mange and Otvos, 2005).

Conglomeritic deposits occur abundantly in the northeastern part of the Niger Delta Basinwhere they are being quarried for construction purposes. No previous studies have been done to ascertain the provenance of thesesediments. A number of studies have been carried out to deduce the environment of deposition (Amajor, 1986; Petters, 1989; Inyang, 2001). This work is therefore aimed at determining the provenanceof the conglomeritic deposits using petrographic, heavy mineral and palaeocurrentanalyses.

Geologic setting

The conglomeritic deposits of the Ameki Formation occur in the northeastern part of the Niger Delta Basin, Nigeria (fig. 1, 2). The Niger Delta Basin is a progradational depositional complex within the Cenozoic era. It is located in the southern part of Nigeria and covers an area of about 75,000 square kilometers. It is among the World's largest petroleum Provinces and has been rated as the sixth largest oil producer and twelfth giant hydrocarbon Province. It extends from the Calabar Flank and the Abakaliki Trough in eastern Nigeria to the Benin Flank in the west and opens to the Atlantic Ocean in the Gulf of Guinea as an extension from the Benue Trough and Anambra Basin. To the southeast, the important line of volcanic rocks comprising the Cameroon volcanic zone (mountain) and Guinea ridge form another boundary. The western limit of the Niger Delta Basin is the Okitipupa Ridge (Nwajide, 2013).

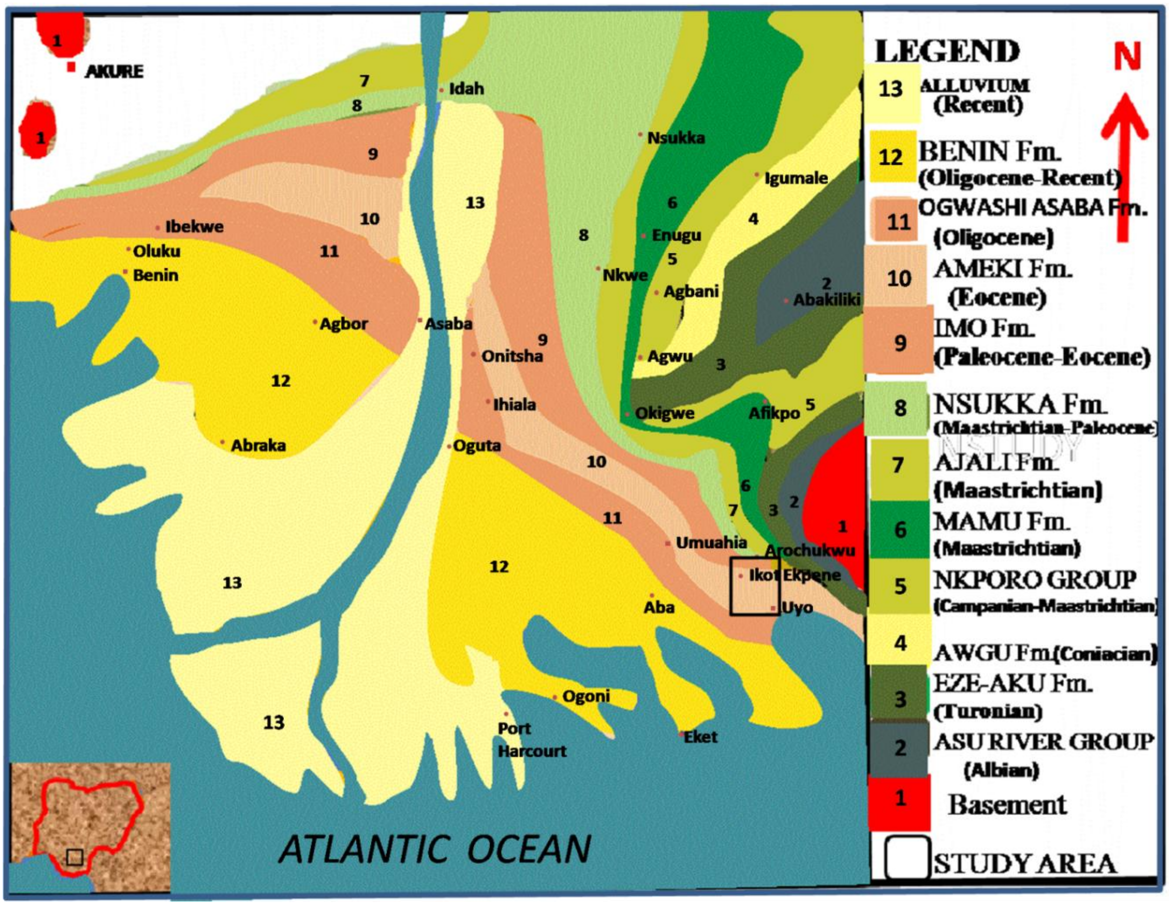


Figure.1: Geological map of southern part of Nigeria showing the study area.

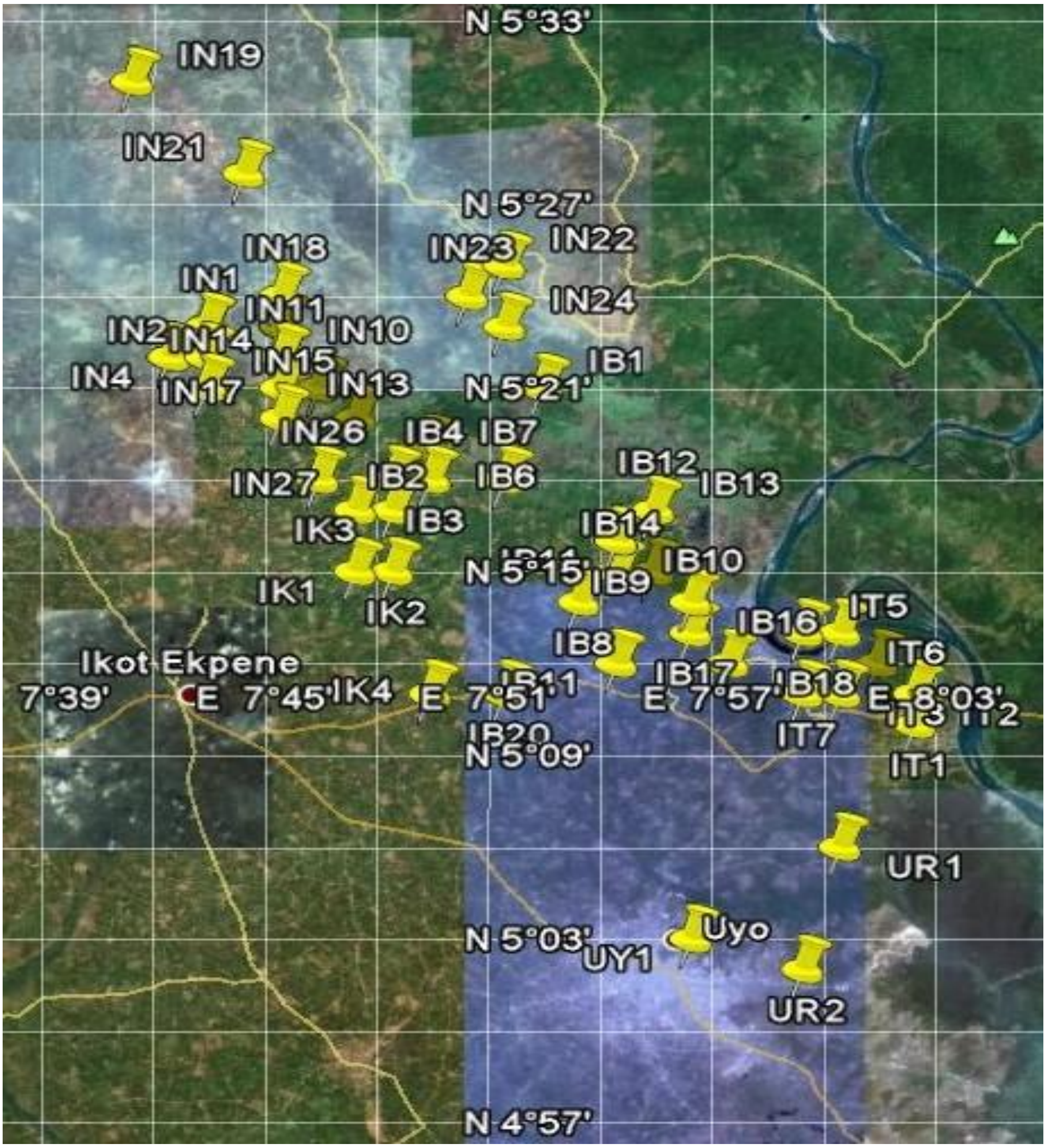


Figure2: Sample location map

The origin of the Niger Delta Basin and other southern Nigeria sedimentary Basins is traced to the separation of the Afro-Brazilian plate during Early Cretaceous. The separation of the Afro-Brazilian plate initiated the opening of the south Atlantic during the Late Jurassic to Early Cretaceous times and reached Nigeria by Mid-Cretaceous, resulting to the evolution of the Benue Trough (Murat, 1972; Hoque and Nwajide, 1984; Ojoh, 1992; Reyment, 1965; Nwachukwu, 1972; Olade, 1975; Kogbe, 1976; Petters, 1978; Wright, 1981; Benkhelil, 1982, 1989). The Benue Trough is a continental scale intraplate tectonic megastructure which constitutes part of the Mid-African Rift system (Ojoh, 1992). The tectonics of the Benue Trough is controlled by transcurrent faulting (sinistral wrenging) (Benkhelil, 1989). Genik, 1993 suggested that the Benue Trough is part of the West and Central African Rift System that opened as a sinistral wrench complex. The Benue Trough is considered as the failed arm of a Y-shaped triple junction that initiated the opening of the south Atlantic Ocean and is thus regarded as an aulacogen (Hoffman *et al.*, 1974; Olade, 1975; Hoque and Nwajide, 1984). The Benue Trough occursas a NE-SW trending linear depression with about 4500m thick Cretaceous sediments (Olade, 1975). Hoque (1984) and Benkhelil (1989) suggested magmatic activity during the opening and closing of the Benue Trough which led to the deposition of Abakaliki pyroclastics. Contact metamorphism occurs around the intrusive bodies while low grade metamorphism affected most deformed areas in Abakaliki

(Benkhelil, 1989). The Niger delta complex is a regressive off lap sequence which prograded across the southern Benue Trough and spread out onto cooling and subsiding oceanic crust which was formed as Africa and South America separated.

The southern Nigeria sedimentary basinshave been the scene of three depositional cycles. The first began with a marine incursion in the middle Cretaceous and was terminated by a mild folding phase in the Santonian time. The second included the growth of a proto-Niger delta during the Late Cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger Delta (Short and Stauble, 1967).

At the beginning of the Tertiary, the sea transgressed the whole of southern Nigeria, terminating the progradation of the Upper Cretaceous Niger delta and separating it stratigraphically from the modern Niger delta which began to form in the Eocene.

The main rock-stratigraphic unit of Paleocene age is the Imo Formation. The Imo Formation ranges into the early Eocene (Stolk, 1963) and is overlain by the sandy Ameki Formation which marks the onset of a regression and the formation of the modern Niger delta. East of the Niger, the Ameki Formation is very heterogeneous, consisting of alternating sandstone and shale, sandy or calcareous shale, marl, and a few fossiliferous shale and limestone beds (Figure 1). These abrupt, irregular alternations indicate deposition in a shallow marine environment with sediment supply from the nearby coast. During the Middle and Late Eocene, the sedimentary rocks became increasingly sandy, marking the onset of a general regression and of deltaic deposition.

In the Middle Eocene, major depocenters initiated in the Paleocene to Eocene in the Anambra Basin, Afikpo syncline, and the Ikang Trough were the sites of the deltaic outbuilding with the Niger-Benue and the Cross River drainage systems accounting for the bulk of the sediment supply. Both drainage systems merged at the end of the Oligocene and formed the present day Niger delta. Simple growth faults were initiated in the Oligocene (Whiteman,1982).

During the Miocene, uplift of the Cameroon mountains provided a new and dominant sediment supply through the Cross River, thus constructing the Cross River Delta. The shoreline progressively migrated seaward during deltaic progradation. This was greatly accelerated in Miocene to Pliocene times with an attendant increase in growth faulting and large scale diapiric movement of the Akata Shale. Deltaic growth declined in the Late Pliocene to Pleistocene during a major drop in sea level, with sediments by- passing into deep sea fans. A Late Pleistocene transgression flooded the Plio-Pleistocene upper and lower deltaic plains. As sea level stabilized, a new regressive sequence developed.

The youngest stratigraphic unit is the Benin Formation of possible Miocene to Recent age. The unit consists predominantly of yellow and white continental sand, alternating with pebbly layers and a few clay beds (Reyment, 1965).

Short and Stauble, 1967 defined three lithostratigraphic units in the Tertiary of the Niger Delta (Table. 1). The basal Akata Formation is predominantly a marine shale sequence with silty and sandy horizons laid down infront of the advancing delta. The shales of the Akata Formation probably extend over the whole delta area and have been deposited from the Palaeocene to Recent.

The Agbada Formation consists of alternating sandstones and shales deposited at the interface between the Lower deltaic plain and marine sediments of the continental shelf fronting the delta. Generally, the upper part of this formation is sandier than the lower part, indicating a general seaward advance of the delta. The age of the Formation varies progressively from Eocene in the north to Recent in the south at the present delta surface. Virtually all the hydrocarbon accumulations in the Niger delta occur in the sandstones of the Agbada Formation trapped in rollover anticlines fronting growth faults which were generated contemporaneously with the deposition of the sediments. The shales of the formation form impermeable barriers against further upward migration of the hydrocarbons. The same shales are also the most obvious source rocks for the hydrocarbons

The Benin Formation is predominantly a sandstone sequence with few shale intercalations which become more abundant towards the base. The sands of the formation are largely deposits of the continental Upper deltaic plain environment ranging in age from the Oligocene in the north to their Recent equivalents in the modern delta.

The conglomeritic deposits in the study area form part of the Ameki Formation. It consists of ten sedimentary facies defined on the basis of textural attributes, lithology and sedimentary structures. These lithofacies were further grouped into three facies associations. These facies associations are interpreted as sediments deposited in the following environment of deposition: braided fluvial channels, braided fluvial floodplain and estuary Udo (2018). Table 2 shows the summary of the lithofacies and the associated depositional environments of the conglomeritic deposits in the study area.

Table 1: Stratigraphic correlation of Tertiary Formation in the Niger Delta (modified after Reyment, 1965)

Age	**Surface Formation**	**Subsurface Eqivalent**	**Broad Depositional Environment**
Pliocene-Recent	Coastal Plain Sands	Benin Formation, Afam and Qua Iboe Clay Member	Continental
Miocene-Recent	Ogwashi-Asaba Formation	,,	,,
Eocene-Recent	Ameki Formation	Agbada Formation	Paralic
Paleocene-Recent	Imo Formation	Akata Formation	Marine

II. METHODOLOGY

The methods used in this study are petrographic, heavy mineral and paleocurrent analyses.

Sandstone petrography

A total of eleven unconsolidated sandstone samples were impregnated with Epo-tek and thin sectioned. The thin sections were then studied with a zeiss polarizing microscope to determine the mineralogical composition and textural attributes. The method of point counting was used to obtain the modal data (Dickinson, 1979; Ingersoll et al., 1984; Zuffa, 1985). This method involved noting the number of times each kind of mineral species came under the intersection of the cross hair. Traverses were arranged to cover the slide and the lower limit of 300 count was set. Before counting, each slide was examined in order to determine the compositional elements to be counted. Also a few grains were randomely selected and the size and roundness measured, the latter by comparing with Power (1953) roundness chart. Fabric elements such as porosity, contacts and grain orientation could not be examined because the grains were dispersed. For the same reason, the void filler-cement and matrix could not be noted in their naturally occurring conditions. Perhaps the negligible small grains noted in thinnest sections may be taken to represent the matrix elements which are normally defined only on the basis of the size being less than 0.063mm. The rare iron oxide cement seen in most of the slides probably represent the dispersed ineffective cement.

Heavy mineral analysis

A total of 20 unconsolidated sandstone samples were prepared for heavy mineral analysis.The samples were dry sieved in order to obtain materials in 0.125 to 0.063mm range (Von. Eynatten and Gaupp, 1999). 15g of each sample was soaked in sodium hexametaphosphate solution prepared by dissolving 40g of sodium hexametaphosphate in 1litre of distilled water. The soaked samples were left overnight before being washed with distilled water. Heavy liquid, bromoform was poured into a separatory funnel until the funnel was half fullof the liquid. This was done in a well ventilated hood. The washed sample was poured into the separatory funnel containing bromoform and stirred thoroughly in order to wet all particles and disperse air bubbles. The particles were allowed to settle. After heavy minerals have settled to the bottom of the separatory funnel, the pinch-cock was opened to allow heavy mineral particles to drop onto filter paper in the lower funnel. The pinch cock was then closed so that minerals floating in the remaining heavy liquid remain in the separatory funnel. After heavy liquid had drained from filter paper into used heavy liquid bottle below, the filter paper was removed and placed upside down in porcelain dish containing acetone. The heavy mineral fraction was then dried, weighed and mounted on glass slides for compositional determination and provenance studies.

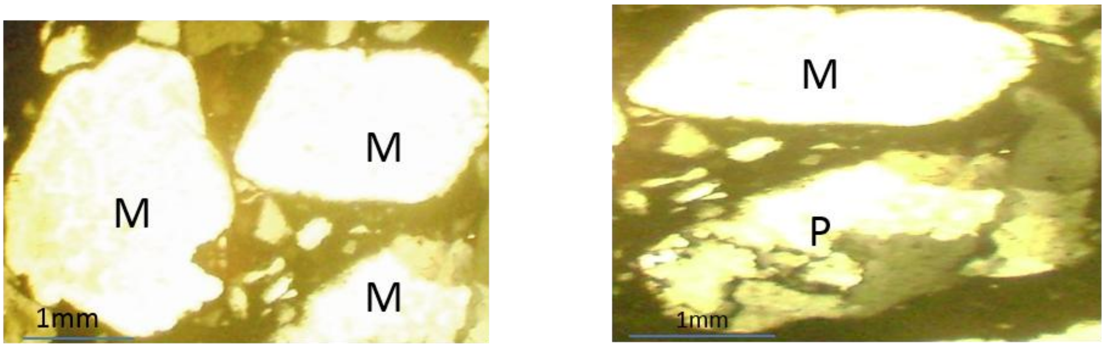
Paleocurrent analysis

Azimuth and dip of crossbedded sandstones were measured in the field using a compass clinometer. The values obtained were then plotted on a rose diagram to determine the provenance and the direction of the ancient current flow.

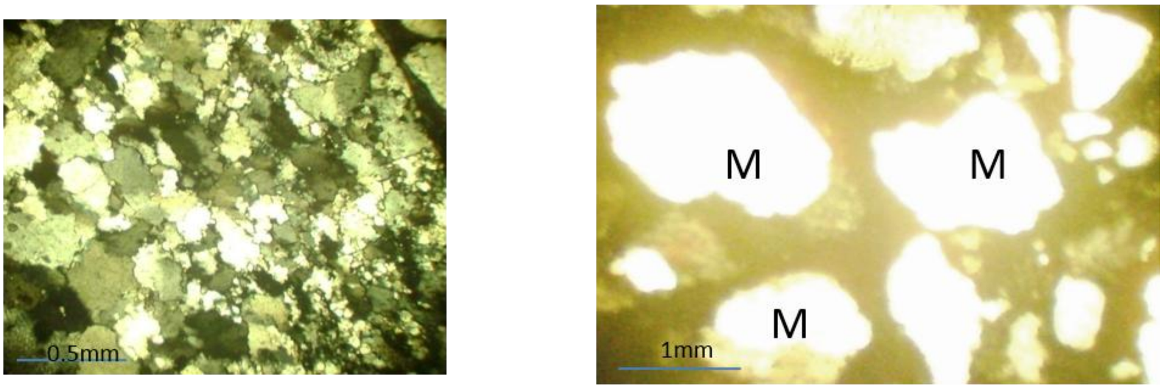
III. RESULTS

Petrology of the sandstone

The conglomeritic deposits have about 70% conglomerates 10% sandstone, 10% mudstone and10% claystone. The sandstone is fine to coarse grained, pebbly, poorly sorted, unconsolidated and friable. Classification of the sandstone was carried out using Pettijohn, 1975 classification scheme. Major detrital framework components of the sandstone (fig. 3, table 3) were used to construct a QFL ternary (fig. 4). The petrographic features of the sandstone units studied are summarized in Table 3. Modal analysis indicates that the sandstone fabrics are composed of 94 to 98% framework elements and 2 to 6% ferruginous cement/matrix content. Most of the samples had 100% monocrystalline quartz. However, two of the samples had up to 50% polycrystalline quartz. The polycrystalline quartz grains contain numerous elongate crystals that exhibit smooth, crenulated or sutured boundaries. Feldspar and rock fragments are absent. The sand grains range in size from 0.06mm to over 2.41mm. The grains are angular to subrounded.



Sample IB6S1 **Sample UR1S1**



Sample IN26S1 **Sample IT5S3**

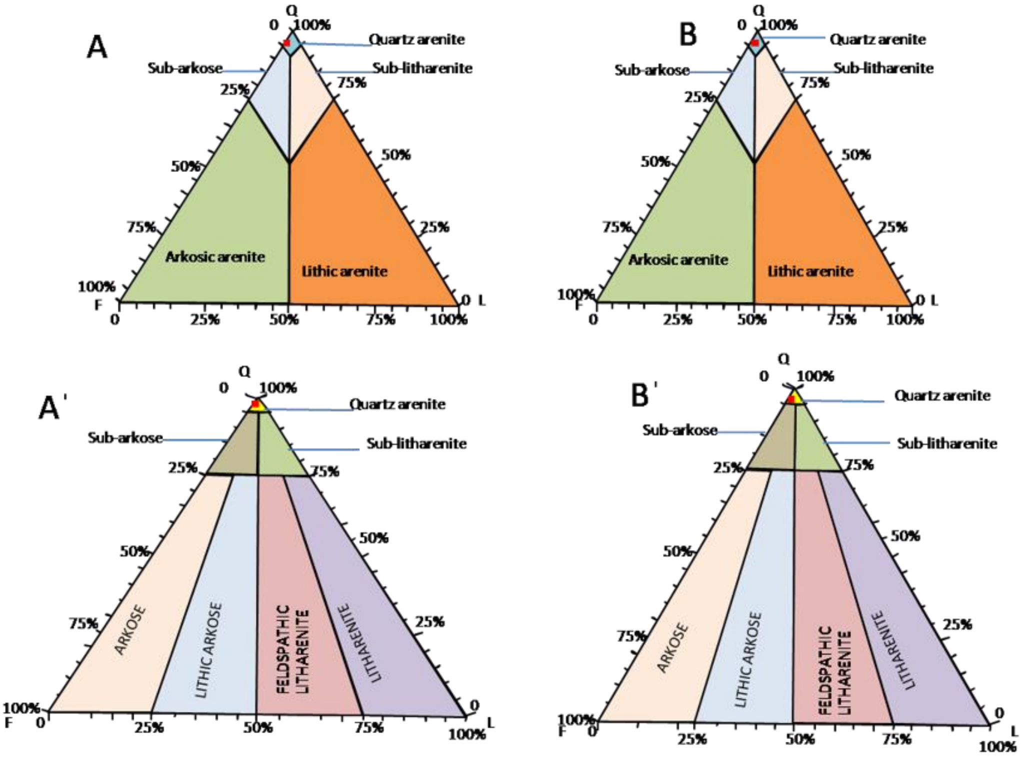
M – Monocrystalline quartz, P – Polycrystalline quartz

Figure. 3: Thin section photomicrographs of selected samples from the study area

Table 3: Petrographic characteristics of selected sandstone samples

SAMPLE NO.	FABRIC	MATRIX/CEMENT CONTENT	ROUNDNESS	% PQ AND MQ GRAINS	TEXTURAL MATURITY	SIZE
IB6S1	100% quartz, framework supported	6%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.10mm – 1.35mm
IN14S1	100% quartz, framework supported	2%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.16mm – 1.73mm
IN13S3	100% quartz, framework supported	5%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.12mm – 1.74mm
UR1S1	100% quartz, framework supported	2%	Subangular to subrounded	MQ = 50% - nonundulose PQ = 50% - undulose	Immature	0.23mm – 2.41mm
IT5S3	100% quartz, framework supported	6%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.13mm – 1.52mm
IN7S1	100% quartz, framework supported	2%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.06mm – 2.27mm
IN26S1	100% quartz, framework supported	3%	Angular to subangular	MQ = 5% - nonundulose PQ = 95% - undulose	Immature	0.18mm – 2.10mm
IN8S2	100%, quartz, framework supported	5%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.13mm – 1.10mm
IK4S1	100% quartz, framework supported	3%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.17mm – 1.24mm
IN1S2	100% quartz, framework supported	4%	Angular to subangular	MQ = 100%, nonundulose	Immature	0.13mm – 1.30mm
IN6S1	100% quartz, framework supported	2%	Subangular to subrounded	MQ = 100%, nonundulose	Immature	0.20mm – 0.98mm

MQ – monocrystalline quartz PQ - polycrystalline quartz



The sandstones are quartz arenite. Each point is a plot of 11 sandstone samples

Figure. 4: (A, B) Petrographic composition of sandstone in the study area plotted on QFL (Q = quartz, L = feldspar, L = lithic fragment) diagram (after Pettijohn, 1975). (A'B') Petrographic composition of sandstone in the study area plotted on QFL (Q = quartz, L = Feldspar, L = lithic fragment) diagram (after Folk, 1980).

Heavy mineral analysis

The suite of heavy minerals (Table 4, figure 5, figure 6, figure 7) consists of thirteen species – three opaques and ten nonopaques. The opaques predominate, comprising about 46% of the entire suite. Among the opaques, magnetite is preponderant.

The nonopaques comprise about 54% of the suite. Two assemblages are easily distinguished – the ultrastables and metastables. The ultrabasic assemblage consists of zircon, tourmaline, and rutile. They make up about 47% of the suite and 87% of the nonopaques. They occur in virtually every sample. Zircon is the commonest of these. It occurs as small euhedral grain with bipyramidal terminations.

The metastsbles are all the other species – kyanite, sillimanite and garnet. Garnet is the most prominent being up to 11% of the nonopaques, and was recorded in almost all samples. It occurs as small anhedral, concoidally fractured, coloureless to pale pink grains usually extinct in crossed polars. Kynite and sillimanite are very scarce in the samples. Kynite commonly occurs as large, colourless, anhedral, but frequently rectangular grains. Sillimanite occurs as elongate crystals with fine needles in parallel arrangement.

Table 4: Heavy mineral composition of samples from the study area

Sample Number	Hyp	Au	Hm	Il	Ru	Mag	Ga	Ep	Tr	Zr	Hb	Si	Ky	ZTR
IB3S1	0.0	0.0	1.4	3.9	0.8	36.4	9.7	0.0	27.5	19	0.0	0.8	0.0	81.8
IB3S2	**0.0**	**0.0**	**5.8**	**9.4**	**0.9**	**31.5**	**7.3**	**0.0**	**59.6**	**24.9**	**0.0**	**0.3**	**0.3**	**91.5**
IK4S1	0.0	0.0	4.5	0.0	0.0	56.0	8.6	0.0	18.8	10.5	0.0	0.0	1.5	74.4
IK3S1	0.0	0.0	6.6	3.1	0.0	23.8	8.5	0.0	18.8	39.2	0.0	0.0	0.0	87.2
IN25S1	0.0	0.0	1.7	1.2	0.6	43.2	4.1	0.0	17.5	31.4	0.0	0.1	0.2	91.8
IN25S2	0.0	0.0	1.6	1.0	0.5	57.6	3.6	0.0	18.2	16.9	0.0	0.0	0.6	89.4
IB4S2	0.1	0.5	1.6	0.5	0.5	40.3	4.4	0.3	36	15.6	0.03	0.1	0.2	90.2
IN7S1	0.0	0.1	1.8	0.6	0.2	39.8	5.0	0.0	44	8.1	0.0	0.2	0.2	90.5
IN7S2	0.0	0.0	8.8	17.5	0.0	28.1	0.0	0.0	45.6	0.0	0.0	0.0	0.0	100
IB4S1	0.0	7.1	3.1	0.3	0.3	49.5	5.6	0.0	18.9	13.9	0.0	0.6	0.6	70.4
IN26S1	0.0	0.0	19.0	0.0	0.0	53.3	4.8	0.0	23.8	0.0	0.0	0.0	0.0	83.2
IN14S2	0.0	0.5	6.8	0.0	3.2	25.0	26.8	0.0	18.2	17.3	0.0	0.9	1.4	56.7
IN14S1	0.5	0.0	4.1	0.0	0.0	28.7	32.3	0.0	19.5	12.3	1.0	1.0	1.0	47.7
IN10S5	0.4	0.0	2.1	0.0	1.0	32.2	1.5	2.1	39.7	1.5	0.0	0.2	20.8	62.8
IN10S4	0.0	0.0	8.6	3.8	0.0	21.5	5.4	1.1	56.5	3.2	0.0	0.0	0.0	90.2
IN10S3	0.0	0.0	15.4	0.0	0.0	61.5	7.7	0.0	15.4	0.0	0.0	0.0	0.0	66.7
IN13S4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
UR2S1	0.0	0.0	12.5	0.0	0.0	29.2	0.0	0.0	54.2	0.0	0.0	0.0	4.2	92.8
IN13S2	0.5	0.5	5.5	2.3	9.6	27.4	6.8	0.9	33.3	10.0	0.5	0.5	2.4	82
IK4S2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0

Abbreviation: mag = magnetite, Tr = Tourmaline , Hyp=hypersthene, Ru=Rutile, Zr=zircon, Ga=garnet, Ky=kyanite, Si=sillimanite, Au=augite, Il=ilmenite, Ep=epidote, Hb=hornblende, Hm = Hematite

Associated Parent Rock: 🟪 Basic igneous rock, 🟦 Basic/acid igneous rock, 🟧 Igneous rock/Metamorphic rock, Acid igneous rock, 🟩 Regional metamorphic rock 🟦

Igneous source = 96.17%

Metamorphic source = 3.38%

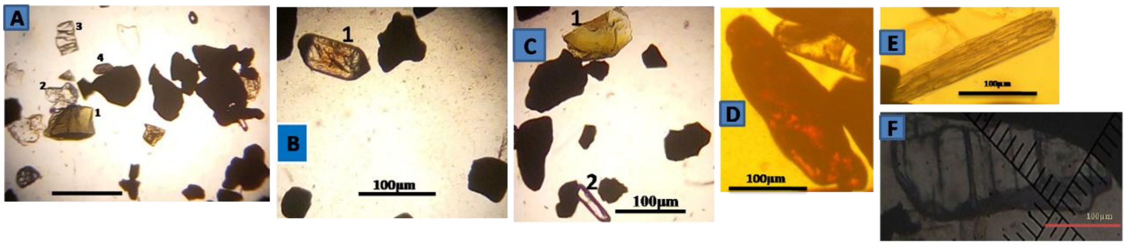


Figure. 5: Images of selected heavy minerals and varieties occurring in the sandstone samples of the conglomeritic deposits. (A) 1 – Tourmaline crystal, 2 – Garnet crystal, 3 – Kyanite crystal, 4 – euhedral Zircon crystal. (B) 1 – Zircon crystal (C) 1 – Tourmaline crystal, 2 – Zircon crystal. (D) Rutile crystal. (E) Silimanite crystal. (F) Kyanite crystal.

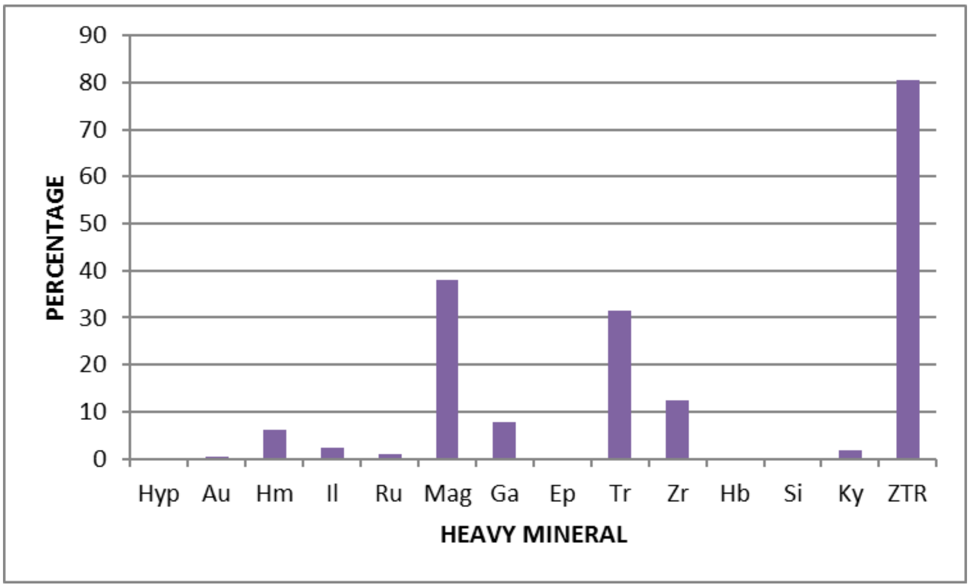


Figure 6: Histogram showing the percentages of the different heavy minerals present in the study area. Mag = magnetite, Tr = Tourmaline, Hyp = hypersthene, Ru = Rutile Zr = zircon, G a= garnet, Ky = kyanite, Si = sillimanite, Au = augite, Il = ilmenite, Ep = epidote, Hb = hornblende, Hm = Hematite

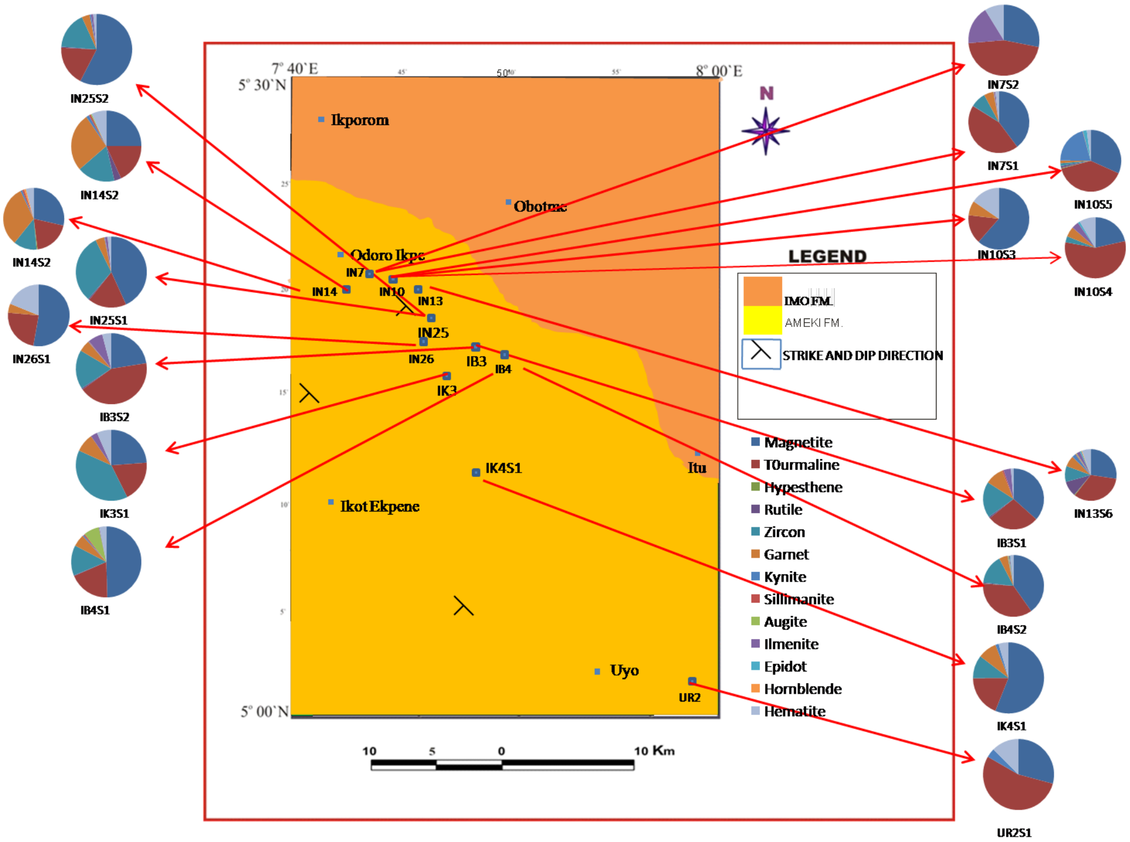
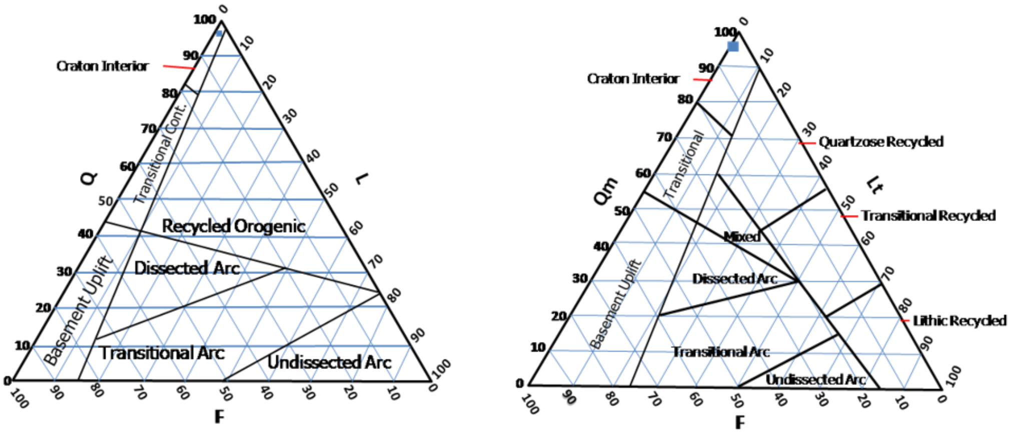


Figure. 7: Map showing the distribution of heavy minerals in the study area

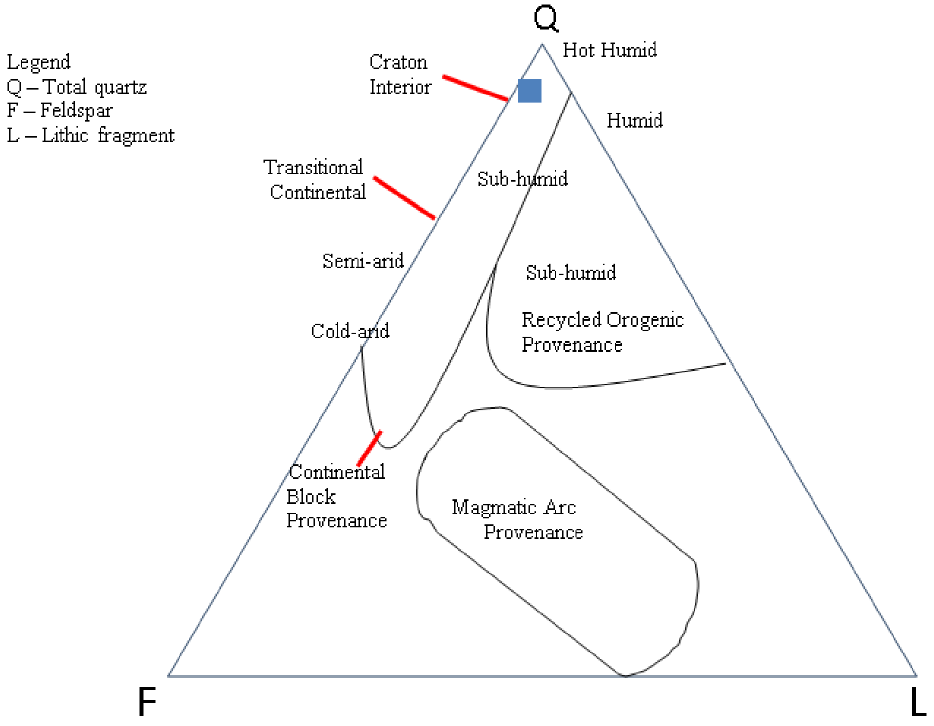
Tectonic and climatic setting

The concept that sandstone composition reflects not only the source area but also the tectonic setting of sandstone accumulation has been expressed quite early by Krynine (1943), and has undergone considerable refinement since then (e.g. Dickinson, 1985). The QFL diagramsof figure 8 and figure 9 show the distribution of detrital modes for the sandstones of the study area. Applying the different compositional fields for the different tectonic and climatic settings as published by Dickinson (1983) and Suttner and Dutter, 1986 respectively, the tectonic source and the climatic setting can be deduced.



The sediment was derived from craton interior. Each point is a plot of 20 samples

Figure. 8: Interpretation of provenance types from petrographic analysis (after Dickinson et al., 1983). Qm is monocrystalline quartz grains, F is total feldspar grains, Lt is total lithic fragments, L is total unstable lithic fragment.



Each point is plot of 20 samples

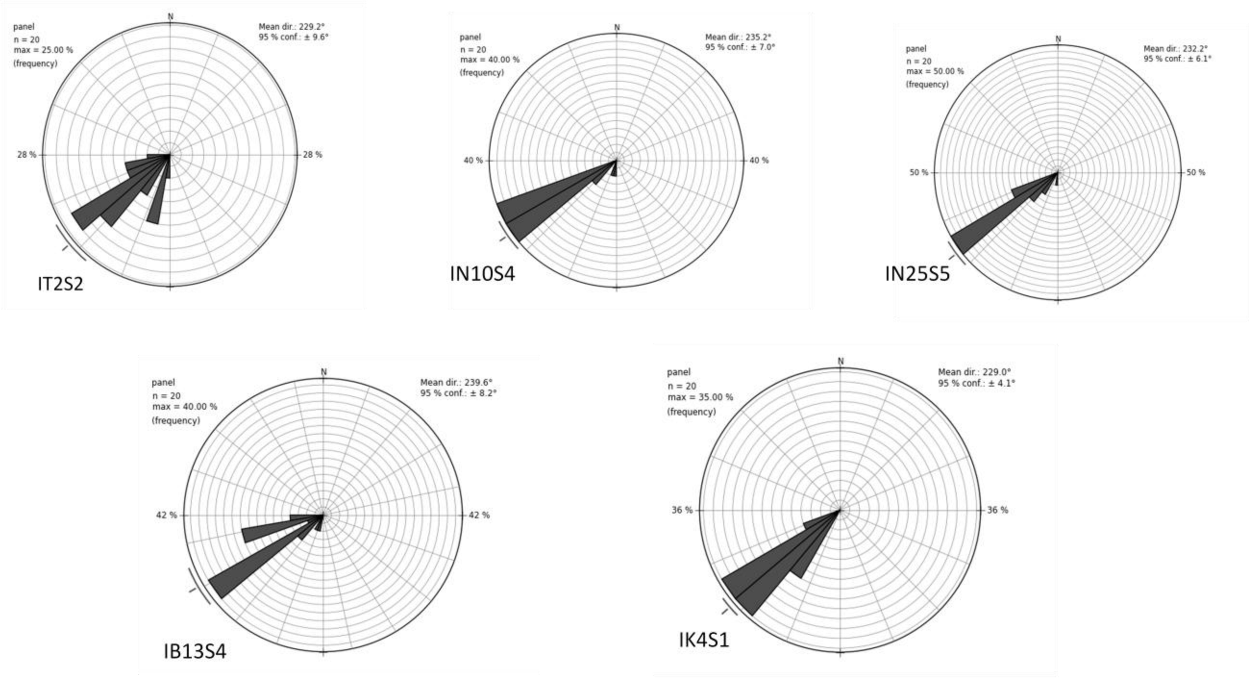
Figure. 9: Interpretation of climatic conditions from QFL ternary diagram for the conglomeritic lithofacies in the northeastern part of the Niger Delta Basin (after Suttner and Dutta, 1986).

Paleocurrent analysis

Paleocurrent data and rose diagrams of crossbedded sandstones lithofacies of the conglomeritic deposits are shown in table 5 and figure 10 respectively. Paleocurrent map of the study area is contained in figure 11.

Table 5: Palaeocurrent data of the sandstone lithofacies of the conglomeritic deposits, northeastern part of the Niger Delta Basin, Nigeria

S/N	Sample IT2S2		Sample IN10S4		Sample IN25S5		Sample IB13S4		Sample IK4S1	
	Azimuth (Ai)	**Dip (D)**	**Azimuth (Ai)**	**Dip (D)**	**Azimuth (Ai)**	**Dip (D)**	**Azimuth (Ai)**	**Dip (D)**	**Azimuth (Ai)**	**Dip (D)**
1	264	22	243	20	236	15	270	20	219	20
2	255	20	245	18	234	20	260	19	212	24
3	257	17	250	22	214	16	252	17	240	20
4	230	18	233	20	231	21	240	21	232	19
5	228	21	230	19	237	19	230	20	229	19
6	220	16	240	21	240	19	225	19	228	24
7	225	17	242	19	243	18	255	17	224	28
8	197	25	235	20	230	20	231	20	220	18
9	195	23	237	18	225	21	234	22	222	21
10	200	19	198	18	239	21	238	19	215	22
11	190	19	240	21	218	16	200	20	230	19
12	240	21	243	19	245	20	251	19	237	23
13	238	24	236	18	228	19	237	17	241	25
14	244	20	231	18	237	19	240	22	231	20
15	241	20	245	20	233	17	241	15	235	18
16	236	18	230	19	244	20	233	19	225	22
17	228	21	190	20	240	21	252	16	242	23
18	234	23	237	18	235	18	231	21	237	21
19	239	20	243	21	232	20	265	20	223	18
20	220	20	250	20	229	20	205	19	227	23



The palaeocurrent pattern is unimodal

Figure. 10: Rose diagrams of the crossbedded sandstone lithofacies of the conglomeritic deposits

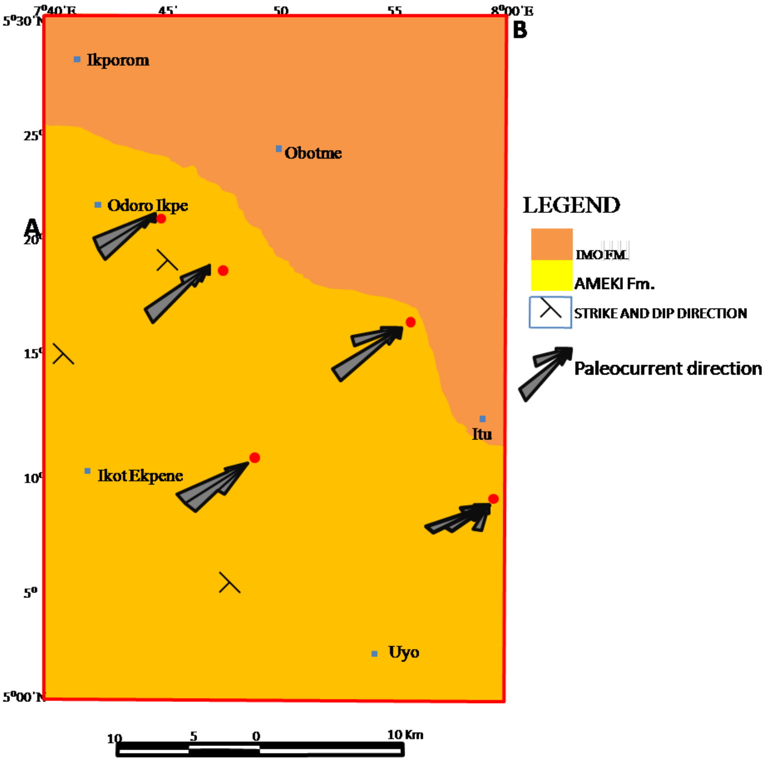


Figure. 11: Paleocurrent map of the study area

IV. DISCUSSION

The sandstones in the study area are classified as quartz arenite. The sandstones are mineralogically mature and texturally submature.The maturity of a sand is the measure of the extent to which the particles have been modified by the forces such as weathering in the source area, effects of transportation, diagenetic processes and intrastrastal solution to which it has been subjected. Textural and mineralogical maturity have been recognized. A sandstone is mineralogically mature if the proportion of quartz grains is very high (Nichols, 1998). In the study area, the percentage of quartz is 100, feldspar 0 and lithic fragment is 0. The mineralogical maturity index (proportion of stable to labile components) is zero since only quartz is present to the complete exclusion of feldspar. The sandstone is therefore, mineralogically mature. According to Hubert, 1962, ZTR less than 75% implies immature sediments and ZTR greater 75% indicates mineralogically mature sediments. The high (ZTR)% suggests that the sandstones are minerallogically mature. The sandstone is poorly to moderately sorted and therefore, texturally submature.

The textural and mineralogical maturity of sediments have both tectonic and climatic implications. A low textural maturity of sediments generally suggests that the source of sediment supply is close to the basin of deposition or a very fast rate of transportation from a region of high relief. The low textural maturity and high mineralogical maturity suggest that the sands were derived from a tectonically stable source region with a warm humid climate in which intense chemical weathering must have played a dominant role in the loss of labile constituents (Folk, 1974, Hoque, 1977). The equancy to subequancy of the quartz grains, the preponderance of monocrystalline nonundulose quartz and the absence of inclusions suggest an igneous source terrain (Cameroon Basement complex) for the sands while the presence of elongate polycrystalline undulose quartz with many crystals in two of the samples indicates minor contributions from the metamorphic basement complex.

The paleoclimatic setting may be inferred from the fate of the feldspars expected to have been present in the source rocks. Their absence in the sands could imply complete destruction in the source area, removal by disintegration during transport or post depositional dissolution. Complete removal at the source before the entrainment of the detritus would imply climatic rigour and/or a source area of low relief. Since the most likely source area is the Cameroon basement complex, the relief was obviously high. Therefore, the feldspars were most probably removed by intense chemical weathering in a hot and humid paleoclimate (Hoque, 1976) The paleoclimatic conditions of the study area can also be interpreted from the compositional maturity of the conglomeritic lithofacies expressed in the QFL ternary diagram using scheme proposed bySuttner and Dutta

(1986) Sandstones with average QFL ratio of 100:0:0 were deposited under hot humid climate and exhibit a high compositional maturity.

The QFL diagram proposed byDickinson et al (1983)shows that the sands were derived from a cratonic source suggesting the predominance of monocrystalline nonundulose quartz.

The unimodal paleocurrent patternshowing a south-west trend indicates that the direction of flow is southwest and the source of the detritus is in the north-east, suggesting that the northeastern granitic basement complex rocks of the Cameroon massif is the source of the detritus.

The individual heavy minerals may suggest provenance. Augite hypersthene and rutile are products of mafic igneous rocks. Rutile also occurs in contact and regional metamorphic rocks. Ilmenite and hematite are products of maficand felsic igneous rocks. Magnetite is a product of mafic and felsic igneous rocks and high rank metamorphic rocks. Tourmaline is a product of acid igneous rock (pink euhedral tourmaline), hydrothermal emanations (blue tourmaline) and low rank metamorphic rocks (tourmaline with small pale – brown carbonaceous inclusions). Hornblende is a product of felsic igneous rocks, hydrothermal emanations and high grade metamorphic rocks (blue-green hornblende). Zircon is a product of felsic igneous rock. Garnet is a product of hydrothermal emanations (veins, pegmatite) and high grade metamorphic rocks. Epidote, kyanite and sillimanite are products of high grade metamorphic rocks. Epidote also occurs in mafic igneous rocks and hydrothermal emanations (Pettijohn, 1975; Friedman and Sanders, 1978; Mange and Maurer, 1992). The best indicators of provenance are in the assemblages. Augite, epidote, hypersthene, ilmenite, magnetite, garnet, rutile, tourmaline, zircon, hematite and hornblende assemblage indicates an igneous source rock while kyanite, sillimanite and epidote assemblage are indicative of high grade metamorphic rocks. The general paucity of kyanite, sillimanite and epidote in the sands indicate minor contributions from a metamorphic source. It would appear therefore that the mineral components of the sands were derived mainly from the igneous terrain.

V. CONCLUSION

The petrographic and provenancestudiesof theconglomeritic lithofacies of Ameki Formation in the northeastern part of the Niger Delta Basin allow the following conclusions:

1. The sands are fine, medium and coarse grained, moderate to poorly sorted and angular to subrounded.
2. Feldspars and rock fragments are absent; quartz is the sole framework element. Matrix and cement could not be observed due to the highly dispersed nature of the samples.
3. Monocrystalline nonundulose quartz constitutes about two third of the quartz varieties. The monocrystalline nonundulose variety makes up 82% while polycrystalline quartz constitutes 18% of the sands.
4. There are three opaque heavy minerals and ten non opaque heavy minerals. The opaques include ilmenite, magnetite and hematite and constitute 46% of the suite. The non-opaques include kyanite, sillimanite, epidote, garnet, zircon, tourmaline, augite, rutile, hornblende and hypersthene.
5. The sands contain only quartz as the framework element, and neither cement nor matrix could be made out in thin section. There appears to be no suitable classification than quartz arenite.
6. The sands are texturally submature (poorly to moderately sorted) and mineralogically mature (94-98% quartz).
7. The sands were derived from metamorphic and igneous sources. The predominance of monocrystalline nonundulose quartz suggests that the sands were derived from an igneous source probably the northeastern granitic basement complex rocks of the Cameroonmassif. The presence of the diagnostic heavy mineral assemblages: kyanite – sillimanite – epidote favours metamorphic origin. The absence of feldspar suggests that the detritus was produced under hot and humid climate. The QFL diagram suggests hot humid climatic condition for the conglomeritic deposits using the model proposed by Suttner and Dutter (1986). The geographical location of the source rocks is the Cameroon Basement Complex.

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