

PROVENANCE OF SANDSTONE ON THE WESTERN FLANK OF ANAMBRA BASIN, SOUTHWESTERN NIGERIA

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ABSTRACT

Petrographic and heavy mineral studies were carried out on clastic deposits that crop out in Ikpeshi, Auchi and Fugar localities in order to determine the provenance of the sediments and the tectonic setting of the source area. The localities are in the western flank of the Anambra basin, southwestern Nigeria. Petrographic study shows that the sandstone deposits are composed of variable amounts of quartz, feldspars and lithic fragments with minor occurrence of authigenic silica and chlorite cements. Quartz is the predominant detrital mineral in all the samples accounting for over 87 % of the total framework composition. The representative samples from all the localities contain 88-94 % quartz, 1-8 % lithic fragment, 1-4 % cement and 0-4 % matrix. Feldspar is present in small amount only in samples from Fugar locality. The sandstones each classify as quartz arenites and sublitharenites. Both opaque and transparent heavy minerals occur in the sandstones. The opaques are magnetite, ilmenite and leucoxene. Together, they account for 35 – 55 % of the total heavy mineral abundance. The transparent heavy minerals are zircon, tourmaline, rutile, staurolite, and apatite listed in order of decreasing abundance. The heavy mineral assemblages in the localities are similar except for the absence of rutile from the sediments of Ikpeshi locality. The heavy mineral grains are sub-angular to rounded. The zircon-tourmaline-rutile (ZTR) index for the sediments from the three localities are generally high and range from 90.5 to 100% indicating high degree of mineralogical maturity of the sandstones. The heavy mineral suites and the petrographic signatures of the sandstones suggest derivation mainly from acid igneous rocks, gneisses and older sandstones in both stable tectonic and recycled orogenic settings. However, the absence of rutile in sandstone from Ikpeshi may suggest derivation from lithologically more restricted provenance.

INTRODUCTION

The western flank of Anambra basin in localities of Ikpeshi, Auchi and Fugar contains a good number of well exposed outcrops of siliciclastics that permit investigation into their provenance and tectonic setting. The study covers the area within the coordinates of latitudes $07^{\circ} 00' N$ and $07^{\circ} 12' N$ and longitudes $006^{\circ} 10' E$ and $E006^{\circ} 36' E$. The importance of constraining sediment provenance in basin analysis cannot be overemphasized. It is a veritable tool for reconstructing a basin's paleogeography through time. Provenance studies of clastic deposits are based on the premise that different tectonic settings contain specific range of mineralogical compositions (Dickinson, 1985). The use of framework mineral composition to identify the tectonic settings of siliciclastics has been demonstrated by many researchers (e.g., Dickinson and Suczek, 1979; Dickinson et al., 1983; Dickinson, 1985). However, because the mineralogy of clastic rocks is considerably altered by weathering processes, transport and diagenesis constraining their provenance using mineralogy alone becomes difficult. This work therefore explores the integrative approach of textural characteristics, heavy mineral analysis and framework mineral composition for the discrimination of sediment provenance and its tectonic setting.

TECTONIC SETTING OF THE ANAMBRA BASIN

The Anambra basin is a sub-basin within the Southern

Benue Trough in southern Nigeria. The trough is an elongate rift basin which trends NE-SW and extends from Niger Delta Basin on the Atlantic coastal margin of West Africa to attain an approximate length of about 800 km (Ofoegbu, 1984). The Benue Trough structurally divides into three segments – the southern Benue Trough, the central Benue Trough and the northern Benue Trough (Fig. 1). Other sub-basins and depocentres along the length of the trough include Gongola, Yola, Mamfe basins, as well as Abakaliki Anticlinorium and Calabar Flank. The sediment infill of the basin youngs southward from Albian in the northern portion of the basin to Tertiary in its southern fringes. The proto Anambra basin existed as a platform which was thinly draped by sediments during the Albian-Santonian times. Tectonic movement in the Santonian times resulted in the structural inversion of the Abakaliki-Benue trough and the concomitant formation of depressions on its two flanks: the small Afikpo Syncline on the southeast and the much wider Anambra basin on the northwest (Benkheilil, 1989; Zaborski, 2000). The Santonian tectonic event saw the westward translation of the depo-axis to the downwarped Anambra basin. Sediment supplies to the newly formed Anambra basin and the Afikpo Syncline were speculated to have been sourced from sediments recycled from the uplifted Abakaliki anticline and sediments derived from weathering of the surrounding crystalline complexes of the Oban Massif and the Southwest Craton. The various lithostratigraphic units in the Anambra basin are Nkporo

Group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Ameki Group and Ogwashi-Asaba Formation (Umeji and Nwajide, 2007). The basin contains commercial quantity of hydrocarbon which is currently being developed and exploited. This study is expected to enhance the understanding of the basin's evolutionary history.

METHOD OF STUDY

The fieldwork involved mapping of sandstone outcrops exposed along road cuts, river channel and burrow pit. Paleocurrent indicators such as azimuths of cross beds and clasts imbrications in conglomerate facies were recorded for paleo-current analysis. Samples taken from selected beds were made into thin sections for petrographic analysis. A total of seven thin sections were made including two from Ikpeshi, two from Auchi, and three samples from Fugar locality.

Fifteen disaggregated samples were selected for heavy mineral separation. Each sample was heated in dilute hydrochloric acid (HCl) for about 15 minutes to eliminate calcareous minerals and to clean the grains. The dried samples were sieved through a 300 microns mesh size. The fraction that passed through the sieve was used for the separation. Bromoform of specific

gravity 2.85 was used as the separating medium. The funnel method was adopted in order to concentrate the heavy mineral grains. Microscopic petrographic point counting of detrital heavy mineral grains was carried out on each slide in order to evaluate the Zircon-Tourmaline-Rutile (ZTR) index of mineralogical maturity of the sandstones.

RESULTS

Seven sandstone outcrop locations herein grouped into three main localities for ease of discussion were understudied. A brief information on the locations of the outcrops is given in Table 1. Location 1 is in Ikpeshi locality; locations 2 and 3 fall within Auchi locality while locations 4, 5, 6 and 7 are grouped under Fugar locality. Virtually all the outcrop sections are composed largely of moderately sorted, poorly indurated to friable sandstone facies except for the outcrop at Ikpeshi which contains a small portion of conglomerate facies near the base of the section and siltstone facies at the top of the section. The bed at the basal portion of the Ikpeshi road cut possesses planar cross bedding. Imbrication of pebbles was also observed and documented at the outcrop. Paleocurrent indicators like cross stratifications are common in some of the outcrops.

Table 1: Outcrop and sample locations. Location 1 = Ikpeshi; Locations 2 & 3 = Auchi; Location 4, 5, 6 and 7 = Fugar locality.

Location	Description of outcrop location	Latitude (Deg. & Min)	Longitude (Deg&Min)	Retrieved Samples
1 (Ikpeshi)	Road cut exposure of massive sandstone located opposite Naseme Army Barracks near Ikpeshi along Auchi-Ibillo Road.	N 7 ⁰ 07.224	E 006 ⁰ 129.380	IKP-1A to IKP-11A;. IKP-1B to IKP-11B.
2 (Auchi)	The locality is situated along Orle River gully. It is located along Auchi- Afuze road behind Union Bank PLC. The river flows southwestwards.	N 7 ⁰ 03.372	E 006 ⁰ 15.261	AU-E1, AU-D1, AU-C1, AU-B1 & AU-AI
3 (Auchi)	Locality is a river channel exposure situated along Ole river channel about 500 m southwest of locality 1.	N 7 ⁰ 03.835	E 006 ⁰ 15.373	AU-E2, AU-D2,AU-C2 ,AU-B2, AU-A2.
4 (Auchi)	Roadcut exposure of sandstone situated between Ayegure and Fugar along Auchi-Agenebode road.	N 7 ⁰ 05.035	E 006 ⁰ 24.544	AY-1
5 (Fugar)	The outcrop is a Roadcut with a lensoidal shape in Fugar. The tabular sets cross-bedded sandstone has been dissected by erosion.	N 7 ⁰ 05.437	E 006 ⁰ 30.915	FU-1, FU-2, to FU-14
6. (Fugar)	Sandstone outcrop exposed at a burrow pit about 2 km east of Fugar along Auchi-Agenebode Road.	N 7 ⁰ 05.530	E006 ⁰ 31.425	OFU-1A, OFU2A to OFU-4A. OFU-1B to OFU-3B
7. (Fugar)	Roadcut exposure of cross bedded sandstone located about 2 km before Othahme along Fugar-Agenebode Road.	N 7 ⁰ 05.571	E 006 ⁰ 32.594	OT-1, OT-2, OT-3, OT-4 to OT-7

Table 2(a): Results of petrographic analysis of representative sandstones from study area showing estimated mineralogical composition in percentage. Qpu – Polycrystalline undulose quartz, Qpn – Polycrystalline nonundulose quartz, Qmu – Monocrystalline undulose quartz, Qpn – Monocrystalline nonundulose quartz, Q - Total Quartz, KF - Potassium feldspar, PF - Plagioclase feldspar, F - Total feldspar, L₁ - Igneous lithic fragment, Lm – Metamorphic lithic fragment, L_S - Sedimentary lithic fragment, C - Cement, L - Total lithic fragment, M - Matrix, RF - Rock fragment.

Sample	Qpu	Qpn	Qmu	Qmn	Q	KF	PF	F	Li	Lm	Ls	L	C	M	Q (%)	F (%)	RF (%)
IKP-5A	5	8	7	67	87	-	-	-	1	-	5	6	3	4	93.6	0.0	6.4
IKP-7A	6	4	13	71	94	-	-	-	-	-	3	3	2	1	96.9	0.0	3.1
AU-A1	3	-	15	74	92	-	-	-	-	-	4	4	3	1	95.8	0	4.2
AU-C1	5	2	11	70	88	-	-	-	-	-	7	7	2	3	92.6	0.0	7.4
FU-5	7	3	13	69	92	3	-	3	-	-	2	2	2	1	95.0	3.1	2.0
FU-12	8	6	12	68	94	3	.	3	-	-	1	1	2	-	96.0	3.1	1.0
OT-2	3	5	10	68	86	1	-	1	-	-	8	8	2	3	90.5	1.1	8.4

The result of the petrographic analysis is presented in Table 2. The predominant mineral in the sandstones consists mainly of sub-angular to sub-rounded quartz occurring both as framework grains and authigenic with subordinate amounts of lithic (or rock) fragments, and opaque minerals. Feldspar is absent in the sandstones except for sandstone from Fugar locality. Little amount of feldspar is present sandstones from locations 5 and 7 both of which are situated east of Fugar. Sandstones from location 7 contains the highest amount of matrix All the analyzed samples are quartz-rich. They contain variable amounts of quartz which range from 93.6 -96.9 % (Ikpeshi locality), 92.6-95. 8 % (Auchi locality), and 90.5-95.0 % (Fugar locality). Overall, the quartz contents range between 92.6 and 96.9 % (Table 2). Most of the

monocrystalline quartz exhibit straight extinction and are smaller than the polycrystalline ones. Most of the quartz grains are monocrystalline while few are polycrystalline with straight inter-crystalline boundary. Authigenic minerals include clay, silica cement, chlorite, and iron oxide minerals. Silica cement occurs as quartz overgrowth that partially or completely rimmed detrital quartz grains. In some cases, the boundary between the grain and the quartz overgrowth is marked by the presence of brown ring of iron oxide dust (Fig. 3). Rock fragments (RF) or lithic fragments (L) are mostly of sedimentary origin. However, a few igneous (plutonic) rock fragments were identified in the sandstone from Ikpeshi locality.

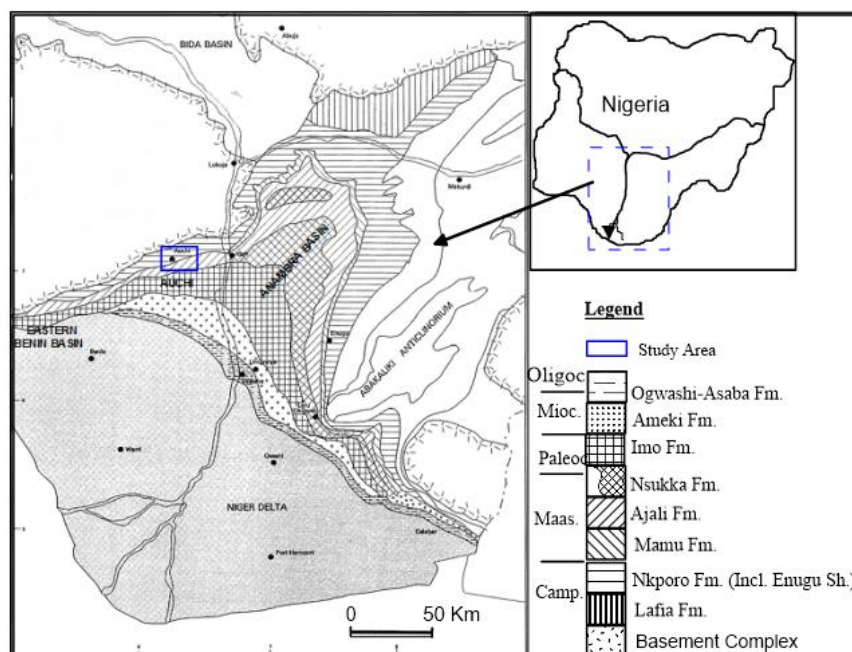


Fig. 1: Geological map of southern Nigeria sedimentary basins showing the position of the study area (Modified after Obaje, 2008).



Fig. 2: Field photograph of the sandstone outcrop at location 5 (Fugar). Note the prominent cross stratification of the beds and friable nature of the rock.

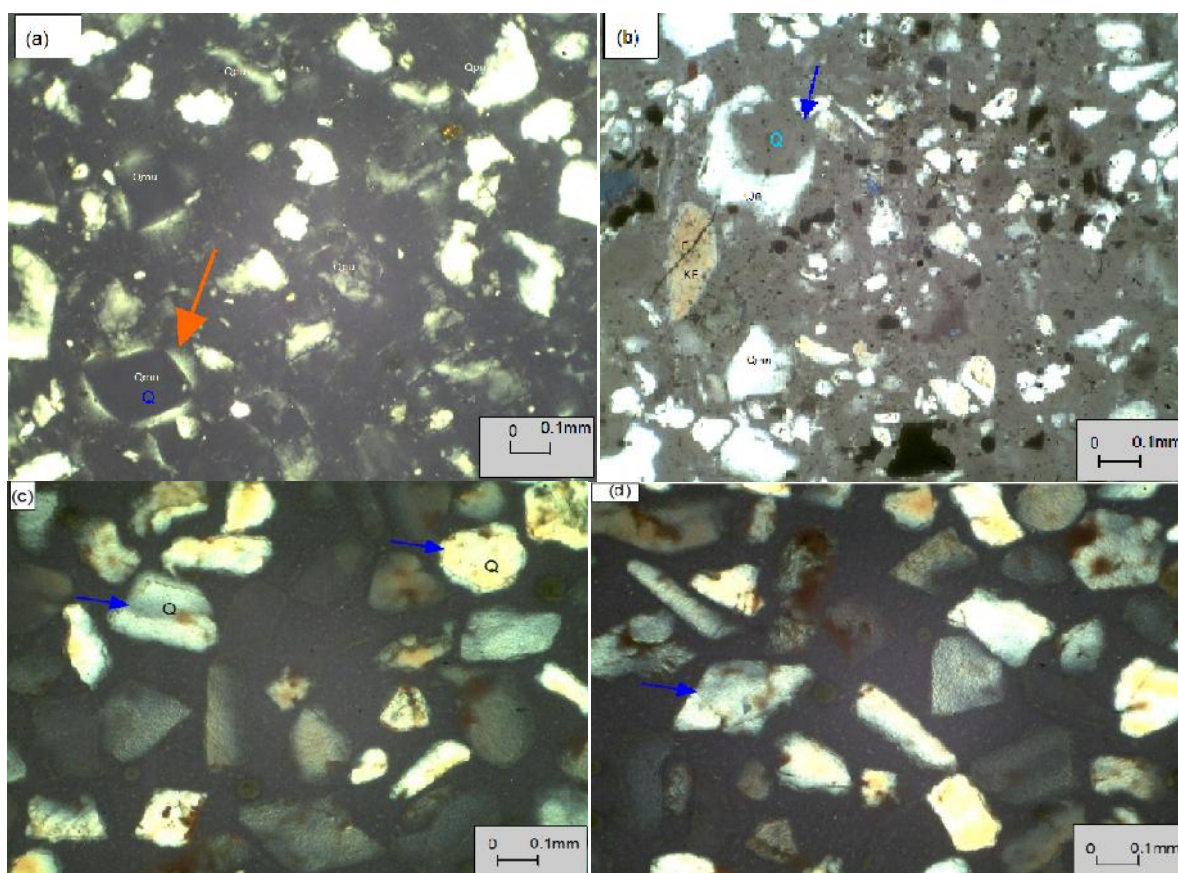


Fig. 3: Photomicrographs of sandstone thin sections: (a) Auchi sample (AU-C1) showing authigenic quartz overgrowth (red arrow) around detrital quartz (labeled Q); (b) Sample from Fugar (FU-7) showing authigenic quartz overgrowth partially rimming (blue arrow) detrital quartz grain (c): Ikpesi sample (IKP-5A) showing authigenic quartz overgrowths (arrows) around detrital quartz grains. Note the brown iron oxide serving as boundary and coating. (d) Euhedral bipyramidal quartz grain (arrow) in Ikpesi sample (IKP-7A) formed as a result of healing of detrital grain during authigenesis (cross polars).

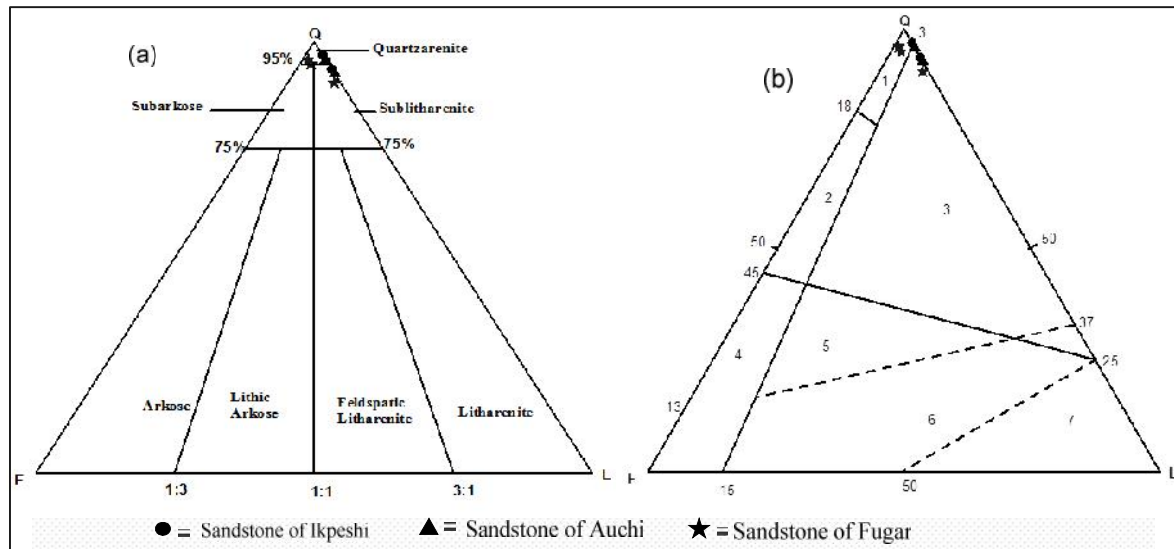


Fig. 4: (a) QFL triangular classification plot of the different sandstones from the study area (After Folk, 1974); (b) Plots of the various sandstone in the study area to generate provenance type using the ternary diagram of Dickinson et al (1983).

The detrital mode of the sandstones is composed of $Q_{90.5-96} F_{0-3.1} L_{1-8.4.5}$. In order to classify the sandstones detrital mode of quartz (Q), feldspar (F) and lithic or rock fragments (L or RF) was plotted on Folk's (1974) QFL ternary diagram (Fig. 4). This scheme indicates that the

sandstones are predominantly quartz arenites with subordinate sublitharenites. The result also shows that the sandstone maturity decreases stratigraphically upward.

Table 3: Heavy mineral data showing the distribution of heavy minerals in analyzed samples expressed in weight percent. Key: Zi - zircon, To - tourmaline, Ru - Rutile, Mag - magnetite, Ilm - ilmenite, St - staurolite, Ap - apatite, P - Present

Sample/Loc.	Zi.	To.	Ru.	Mag.	Ilm.	Mi.	St.	Ap.	ZTR Index (%)
IKP-2B/1	9.1	13.1	-	38.5	39.3	-	-	-	100.0
IKP-5A/1	42.0	2.5	-	33.9	21.6	P	-	-	100.0
IKP-9A/1	32.7	9.1	-	45.6	12.7	P	-	-	100.0
AU-A1/ 2	39.4	9.5	11.6	22.0	9.6	-	7.5	-	89.0
AU-B2/ 3	22.6	8.6	28.3	28.9	11.5	-	-	-	100.0
AY-1 /4	17.6	16.7	22.3	38.6	4.8	-	-	-	100.0
FU-7/5	22.4	8.4	30.5	30.0	8.7	-	-	-	100.0
FU-5/5	30.3	15.7	7.4	25.2	18.3	-	-	3.2	94.3
FU-2/5	33.8	4.9	20.5	26.1	14.6	-	-	-	100.0
FU-3/5	31.0	15.4	13.7	24.8	12.9	-	6.3	-	90.5
OFU-1/6	41.6	-	-	54.3	4.2	P	-	-	100.0
OFU-4/6	20.9	10.1	19.5	36.8	13.0	-	-	-	100.0
OT-1/ 7	24.9	6.5	18.9	43.1	6.7	-	-	-	100.0
OT-4 /7	42.5	5.4	7.2	30.0	15.0	-	-	-	100.0
OT-7 /7	35.6	8.1	12.0	29.7	14.7	-	-	-	100.0

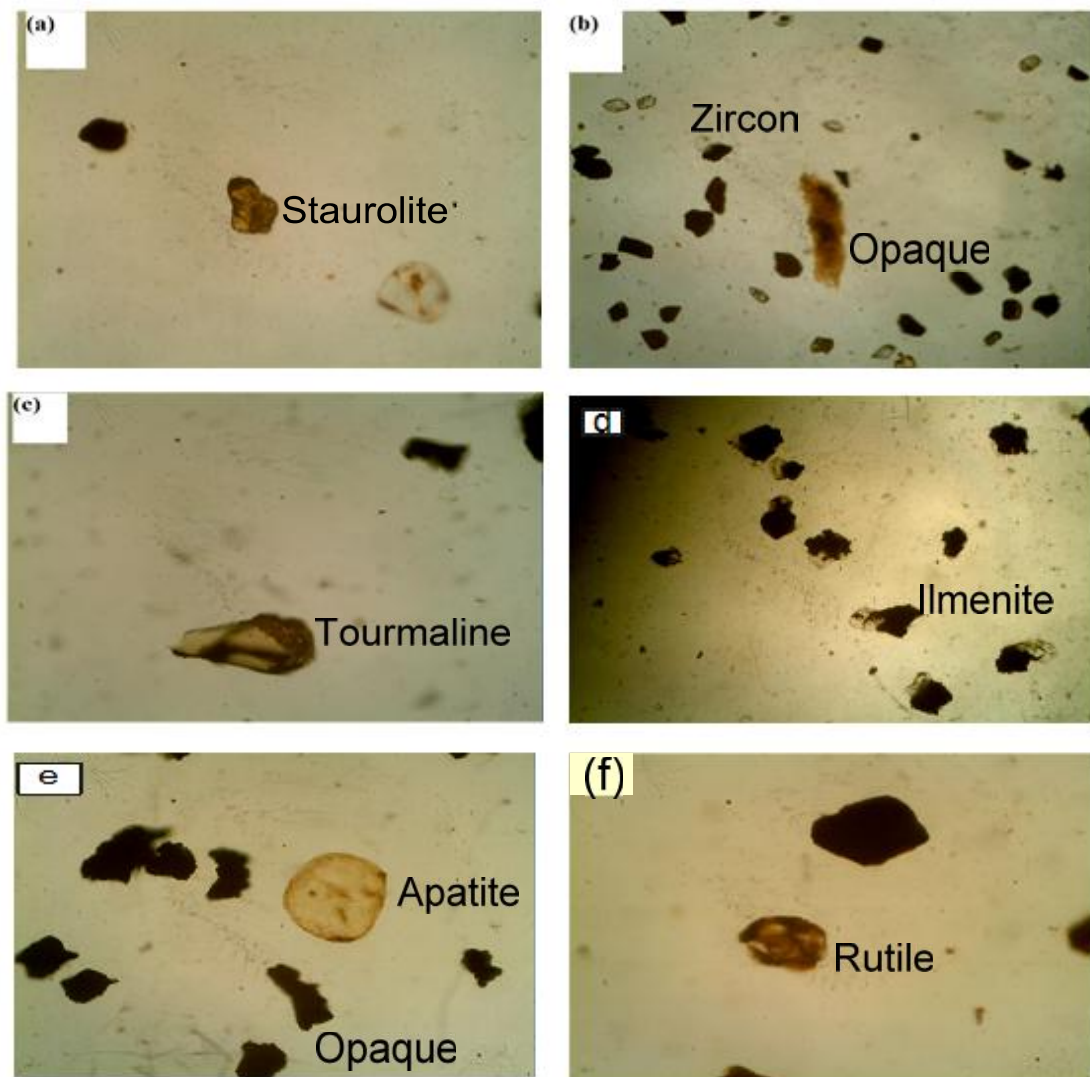


Fig. 5: Photomicrographs (PPL) of some heavy mineral grains in analyzed samples. (b) Staurolite from Auchi (location2, sample AU-A1, (c) Sub-angular tourmaline grain retrieved from Fugar (FU-5) (d) Opaque ilmenite grains showing alteration to leucoxene from the bottommost bed of sandstone outcrop near Ikkpeshi (Ikp-5) (e) Apatite grain from bed 5 of Fugar sandstone outcrop, and (f) Euhedral detrital rutile grain from Fugar (FU-3).

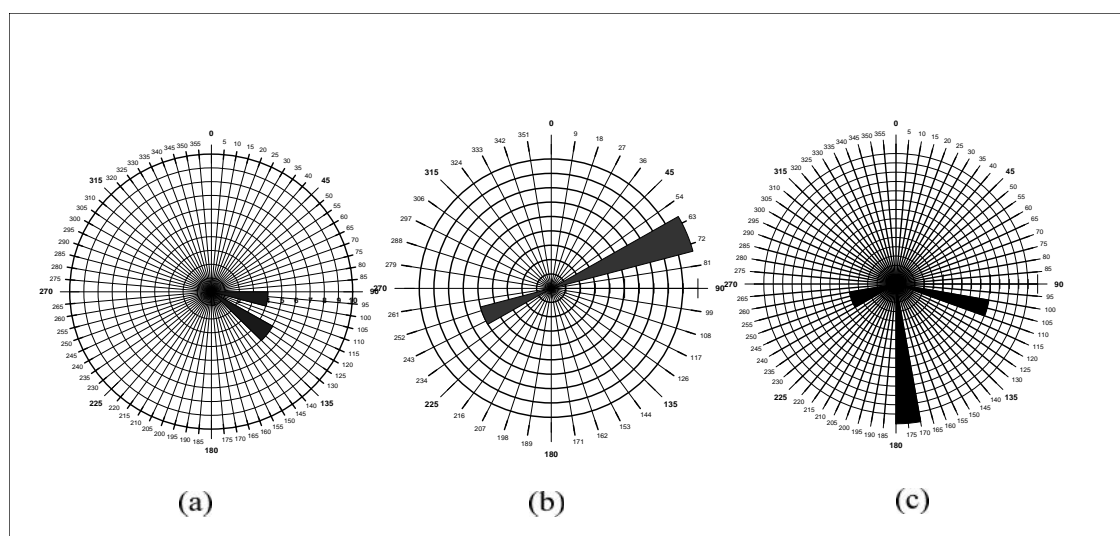


Fig. 6: Rose plots of paleocurrent indicators measured on outcrops. Note the paleocurrent directions varying mainly between SW and SE. (a) - Ikkpeshi locality; (b) - Auchi locality; and (c) - Fugar locality.

Two main heavy mineral groups, the opaque and the transparent heavy minerals constitute the entire heavy mineral suites in all the analyzed sandstone samples. The identified opaque heavy minerals are magnetite and ilmenite alongside its alteration product leucoxene. They occur in variable amounts in all the samples. Together, they account for 31-55 % of the total weight of the heavy mineral present in each sample. Their frequency of occurrence is highest in samples from Ikpesi locality where they constitute about 55 % of the entire heavy minerals present. They are least abundant in sandstone from Fugar area (Fig. 5, Table 3). The transparent heavy minerals are zircon, rutile, tourmaline, mica, staurolite and apatite, listed in order of decreasing abundance. They occur as sub-angular to well-rounded grains. Zircon accounts for about 20 % of the heavy suite in all the sandstones but its amount is variable. Rutile occurs as small, reddish-brown prismatic to acicular crystals with very high relief and high interference colours. It forms about 16 % of the mineral suite. It occurs in samples from Auchi and Fugar localities, but it is lacking in samples from Ikpesi. Tourmaline accounts for about 9 %. Mica is present in minor amount in few samples from Ikpesi and Auchi localities but it is completely absent in samples from Fugar locality. Staurolite and apatite are very rare occurring as minor constituent in samples from Fugar locality (Table 3). The result indicates the dominance of ultrastable heavy minerals over the metastable varieties. The heavy mineral suites of the sandstones from Ikpesi, Auchi and Fugar localities are similar except for the absence of rutile samples from Ikpesi locality.

The zircon, tourmaline, and rutile (ZTR) index of mineralogical modification (Hubert, 1962) was calculated for the analyzed samples (Table 3) by finding the ratio of the combined proportion of zircon, tourmaline and rutile to the total weight of all the transparent heavy minerals present, excluding mica. The average ZTR indices of maturity values are 100.0 %, 96.25 % and 98 % for Ikpesi, Auchi and Fugar sandstones respectively. These values indicate that the sandstones are mineralogically supermature. The micas were not counted because of their flaky nature which makes it moveable by the slightest current of the transporting medium (Folk, 1974; Pettijohn, 1975).

DISCUSSION

The predominance of detrital quartz in the modal compositions of all the sandstones in the study area indicates sediment derivation from siliceous rocks like acid igneous and gneissic rocks. Mineralogically, the sandstones of Ikpesi, Auchi, Fugar and localities in the western flank of Anambra basin classify mainly as quartz arenites and sublitharenites, suggesting that they are mineralogically mature to super mature. The occurrence of minor amount of feldspar in sandstones from Fugar area or its absence in sandstones from Ikpesi and Auchi localities suggest their derivation from low relief cratonic region with a humid climatic setting. Such tectonic setting allows for intense chemical weathering of feldspar whereas the presence of an appreciable amount of feldspar in sandstone indicates either high relief at the source area or arid condition. According to Ullah et al. (2006), the formation of feldspathic arenites on the contrary implies preservation of large quantities of

feldspars during the process of weathering. This may happen due to either (1) very cold or very arid climatic conditions that inhibit the chemical weathering processes, or (2) warmer, more humid climates where rapid uplifts of source area allow faster erosion and sedimentation of feldspars before they can be decomposed.

The detrital modal compositions of the sandstones from the various localities indicate the predominance of non-undulatory monocrystalline quartz (Qnu) with subordinate amount of undulatory quartz (Qu), suggesting greater contribution of clasts from plutonic or volcanic source rocks compared to metamorphic source. Strain-free quartz is indicative of igneous sources while quartz with undulatory extinction suggested metamorphic sources. As Dickinson (1985) noted, polycrystalline quartz usually disintegrates into monocrystalline ones as transport distance increases so that the latter dominates in mature sandstones. Also, the presence of sedimentary lithic fragments and rounded authigenic quartz rimming detrital quartz grain are evidence of recycling of pre-existing sediments and thus underscore contribution from sedimentary provenance. According to Jafarzadeh and Hosseini-Barzi (2008), the presence of sedimentary rock fragments in the sandstone is indicative of sedimentary provenance as they are believed to have been reworked from pre-existing sedimentary rocks. Identification of the tectonic settings of the source area is based on the use of framework mineral compositions of the sandstones. The QFL ternary diagram of Dickinson et al (1983), which relates sand provenance to the tectonic environments, was employed in characterizing the sediment clasts of the study area (Fig.4b). This plot reveals that all the sandstones plot both in the craton interior (continental block) and recycled orogen (quartzose recycled) sources. According to these authors, sandstones plotting in the cratonic field are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins. Its provenance in a stable cratonic terrain is further substantiated by the absence of feldspar in the sandstone. Prolonged exposure of chemically unstable mineral like feldspar to moisture in a stable, low-relief tectonic setting often results in its complete chemical decomposition. This study therefore indicates that climate and relief were the most important factors that controlled the composition of the clastics in the western flank of Anambra basin. The low feldspar content or its absence in some of the samples together with the predominance of detrital quartz suggests intense weathering under humid climatic conditions. The paleocurrent data from outcrop locations 1, 2 and 5 (Fig. 6) indicates that the provenance of the sandstone in Ikpesi locality lies NW of the deposit, suggesting derivation of sediment from the southwest basement massifs. The variations in paleoflow directions may suggest a switch between provenance areas as well as sediment supplies from the adjacent basement complex rocks and the Abakaliki Uplift. According to Amajor (1987) and Umeji and Nwajide (2007), much of the post Santonian clastic deposit in the Anambra basin was presumably derived from the sediments recycled from the Abakaliki Anticlinorium.

The heavy mineral associations reflects source areas dominated by igneous rocks with subordinate metamorphic and sedimentary rocks. The occurrence of granitic clasts in the conglomerate facies at location 1 provides direct evidence for plutonic igneous source for the sandstone outcrop at Ikpeshi. Occurrence of few rounded zircon grains may suggest minor contribution from sedimentary source terrain. As pointed out by Mange and Maurer (1992), zircon, apatite and magnetite are the common minerals characteristic of felsic igneous rocks. Tourmaline, staurolite, biotite and muscovite are typical heavy minerals of low rank metamorphic rocks and igneous rocks. The presence of well rounded zircon, tourmaline, rutile and leucoxene grains either suggests that they derive from a source area located a great distance away from the basin or they derive from older eroded and reworked sedimentary rocks. The high concentration of zircon, tourmaline and rutile relates to their high mechanical and chemical durability. According to Mange and Wright (2007), when clastic sediments get mature, the metastable and unstable heavy minerals wear away with prolonged abrasion, resulting in a composition that is relatively enriched in the ultrastable varieties. Most of the heavy mineral grains are sub-angular while others are rounded. Heterogeneous roundness of grains indicates sediment input from more than one provenance area. The occurrence of metastable heavy minerals like staurolite and apatite in sandstone from Fugar area may suggest less mineralogical maturity for the sandstone compared to those of Ikpeshi and Auchi localities. The similarities in the heavy mineral associations observed in sandstones from Ikpeshi, Auchi and Fugar localities indicate their derivation from lithologically similar sources. However, the absence of rutile in sandstone from Ikpeshi may suggests a lithologically more restricted provenance compared to those from Auchi and Fugar. The ZTR index also indicates that the sandstones are mature to supermature. According to Garzanti and Ando (2007), high ZTR values indicate either sediment derivation from cratonic shields where extensive recycling of ancient sedimentary successions coupled locally with hydraulic sorting is common or it may indicate extensive diagenetic dissolution of less stable species. The nearly uniform proportion of opaques in all samples suggests that the assemblages were controlled mainly by source area lithology and hydraulic fractionation by density.

CONCLUSION

This study employed petrographic, heavy mineral and paleocurrent analyses to investigate the provenance of sandstones on the western flank of Anambra basin. The petrography of the sandstones reveals the abundance of detrital quartz and minor lithic fragments and clay matrix. The siliciclastics are mainly quartz arenites with subordinate sublitharenites. All the analyzed samples contain significant amounts of zircon, tourmaline and rutile except for the absence of rutile in the sandstone from Ikpeshi locality. The ZTR index of mineralogical alteration is generally high, ranging between 95.0 and 100.0 % which indicates that the sandstones are mineralogically mature. The study suggests derivation of sediments mainly from silica-rich (granitic or gneissic) source terrains as well as older sedimentary rocks. These rocks are the southwestern massifs and the

Abakaliki Anticlinorium located NW and NE of the study area.

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