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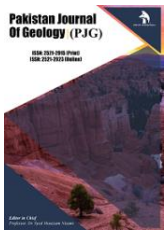

RESEARCH ARTICLE

PROVENANCE STUDIES OF CAMPANIAN-MAASTRICHITIAN OWELLI SANDSTONE OUTCROPPING UNIT IN THE ANAMBRA BASIN SOUTH EASTERN NIGERIA

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ABSTRACT

Provenance study of an outcropping unit of the Owelli Sandstone in Anambra basin, Southern Nigeria was carried out. The outcrop was mapped and logged, A total of four unconsolidated samples were collected from the formation that were impregnated with blue epoxy resin before cutting. Each of the samples were prepared following the techniques employed in thin section analysis. Point counting techniques was employed to quantify the various mineral grains. 200 points were counted for each slide that was viewed under the petrographic microscope. The heavy mineral assemblages which includes garnet, epitode and staurolite suggested medium-grade metamorphic source rock whereas tourmaline, rutile and zircon indicates recycled sedimentary source, igneous and metamorphic source rock. More so, the Owelli sandstone is said to be mature. This deduction arises from the average value obtained from ZTR index data which is in the average range of 67%. The study therefore, indicates that the Owelli sandstone are derived from recycled sedimentary rocks that comes from the Abakaliki uplift in the Benue Trough and the metamorphic and plutonic rocks of the Oban Massif Basement Complex.

KEYWORDS

Provenance, Minerals, Sediments, Anambra Basin

1. INTRODUCTION

Provenance refers to all aspect of the ultimate source of a sedimentary rock; the composition of the source area, its location (distance and direction) and the climate of the source (Schwab, 2003). Provenance involves the interpretation of the lithologic source of sediments and/ or sedimentary rocks. It has been established that fine grained sediments are often the final product of pre-existing clastic sediments, since these particles are stable weathering products and can be recycled through several episodes of burial, uplifts and erosion, depending on the tectonic process of the region (Nagarajan et al., 2017; Potter et al., 2005). We can easily reconstruct the provenance of sediments in a given Formation based on their mineralogical composition present.

Series of analytical techniques such as petrographic modal analysis of arenites has been carried out on the provenance studies of clastic sedimentary rocks (Dickinson, 1970; Zuffa, 1985; 1987; Johnson 1993). Provenance study of siliciclastics sediments is a vital tool in investigating the origin of ancient sedimentary basin. Major and minor elements (minerals) of siliciclastic rocks provides information on the understanding of the types of source rock, paleoweathering conditions, hydraulic sorting and extend of recycling in the tectonic development of the sedimentary basin (Nesbitt and young, 1982; Armstrong-Altrin et al., 2007; Nagarajan et al., 2015; Armstrong-Altrin, 2015).

It has been commonly assumed that these trace elements are referred quantitatively into detrital sediments during the sedimentary process and their concentration reflects the signature of the source rock composition (Nagarajan et al., 2017; McLennan et al., 1980; Bhatia and Crook, 1986; Armstrong-Altrin, 2004). Provenance studies is aimed at assigning sedimentary rock succession in a given formation tom a distinguished petrologic province, a natural sedimentary assemblages of common age, origin of distribution and province.

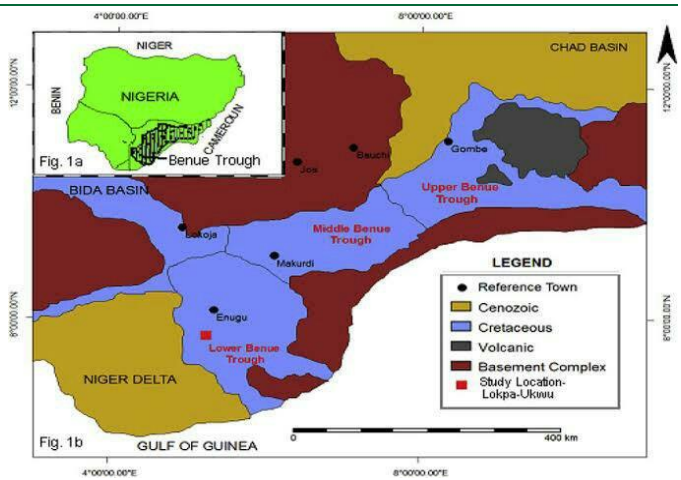

Figure 1: Map showing Geological Units of Benue Trough (Adapted from Short and Staubble, 1967)

2. REGIONAL GEOLOGY OF BENUE TROUGH

Research have it that rifting of the Central West Africa Basement led to the formation of the Benue Trough that began at the Cretaceous time. Early sediment accumulation and deposition at the trough was enhance by river and lake systems. The subsidence of the trough occurred during the Early to Middle Cretaceous where the trough was covered by the sea. There were records of accumulation of sea floor sediments particularly in the Southern Abakaliki rift, under oxygen-deficient bottom condition. The Benue Trough formed at the main link between the Gulf of Guinea and the Tethys Ocean (which was the longest ancient sea that is the predecessor

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of the Mediterranean Sea) through the Chad and Sokoto Basins in the Upper Cretaceous. The trough rose above the sea level closed to the end of this period and developed coal forming swamp, specifically in the Anambra Basin. 6,000m of Cretaceous sediments and volcanic rocks is the estimated volume of rocks contained in the basin. The Benue Trough experienced an uplift during the Santonian tectonic episode and this gave rise to the formation of the Anambra Basin, moving the depositional centre from the trough to the Anambra basin. The Anabra Basin being Cretaceous in age, has an almost triangular shape with sediment thickness of 40,000km^2 (Akaegbobi, 2009).

3. Geologic/Tectonic History of The Study Area

Studies has revealed that the evolution of the Benue Trough is associated with tectonism dated back to the Pre-Albian period. Most of researchers in their work, revealed that, the Abakaliki-Benue Trough was a product of the failed arm during the period of the separation of Africa from South America (Burke et al., 1972; Nwachukwu, 1972). The Mid-Aptian time recorded the opening of these arms in the South Atlantic caused by crustal stretching and downwraping accompanied by the development of coastal evaporite basins. Three main phases that occurred in the Benue Trough that controls the basin fill were identified (Murat, 1970). The first phase of the tectonic began in the Albian time and it was characterized by movements along the NE-SW trending Benue-Abakaliki Trough. These movements gave rise to the appearance of two stable platforms on either side of the uplifted Benue-Abakaliki Trough which are the Anambra platform in the west and the Afikpo to the east. A group researcher made a comparison between the Benue Trough and the Calabar Flank characterized by tectonism and structures (Peter et al., 2004). The major tectonic event as well as significant transgressive and regressive phases were recorded. Another tectonic event which the second phase is recorded gave rise to the folding of the trough which affected the Cretaceous sediments (Benkhelil, 1989). The series of folds recorded in the NE-SW trends gave rise to the formation of the Abakaliki Anticlinorium and the later downwraping of the Anambra Platform to form the Anambra Basin and Afikpo Synclinorium on the west and east of the Abakaliki Anticlinorium respectively (Kogbe, 1976). The depressions became the main depositional targets from Campanian to Paleocene. This folding phase recorded in the Santonian was associated by igneous activities. These account for the massive occurrence of placement of intermediate and basic intrusive rocks found in some localities within the region. The Santonian tectonic phase only affected the Abakaliki Anticlinorium in the Southern Benue Trough which was the second tectonism and it was interpreted to be the closing of an Embrayo Ocean (Burke et al., 1971).

4. Location and Accessibility of The Study Area

The study area lies within longitude 7°27'0" E and latitude 6°1'0"N and falls within the Anambra basin (figure 2). The study area was well accessed by good road network and this helped in accessing the exposed outcrop sections that were studied.

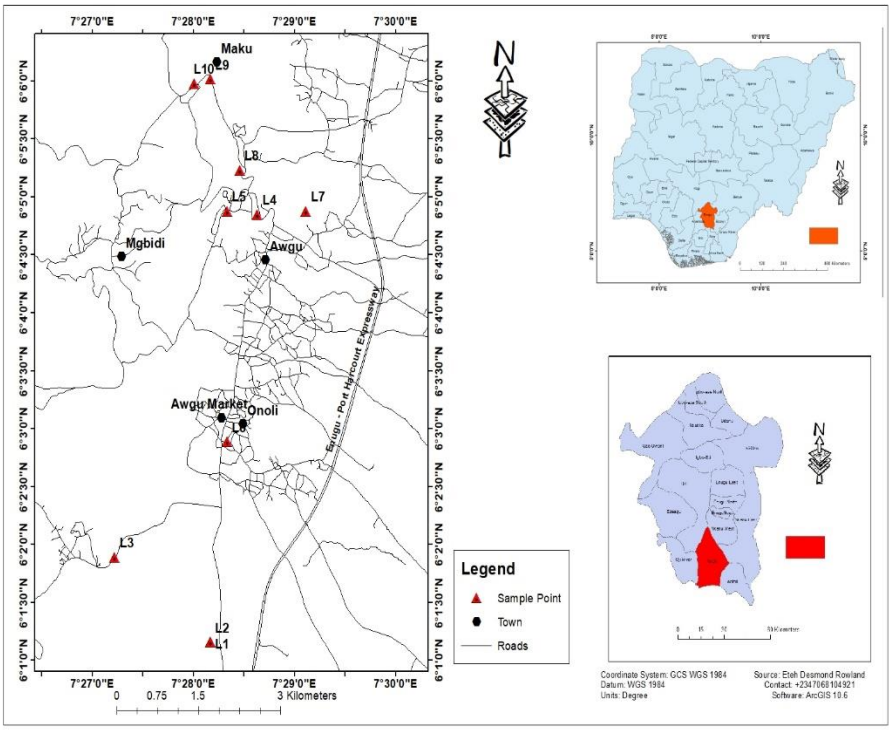

Figure 2: Showing the study area and location

5. Methodology

Provenance study of the Owelli sandstone was based on petrographic investigation and mineral assemblages. A detailed fieldwork was carried out where representative samples of the Owelli Sandstones were collected. Outcrop samples was preferably collected from the basal of the formation to the top of the formation at intervals of 3-4m and Thin sections of the samples were prepared based on the method described (Ireland, 1971). A total of four unconsolidated samples were collected from the formation that were impregnated with blue epoxy resin before cutting. Each of the samples were prepared on a slide using Canada balsam. The slide was then washed with water and allowed to dry before covering with a cover slip and thin sectioned. Point counting techniques was employed to quantify the various mineral grains. 200 points were counted for each slide that was viewed under the petrographic microscope. The purpose of the counting of the grains under the microscope is for the quantitative estimation of the minerals and identification of the grain fabric (Framework), texture, cement, matrix and their proportions. Photo microscope were taken from the prepared sample slide through the mounting of micro photo camera on the microscope. The result from the point counts are summarised in a tabular form.

Calculation of maturity index (ZTR) was done using the Hubert (1962) formula that is shown below:

$$\text{ZTR index} = \frac{\text{Zircon} + \text{Tourmaline} + \text{Rutile} \times 100}{\text{Non-0paque}}$$

6. Results and Discussion

6.1 Lithologic Description of Outcrops

Locality: Awgu-Mmaku Road 1

Rock type: Owelli sandstone

Formation: Nkporo

GSP Coordinates: 06^0 05/ 14.1//N and 007^0 28/ 57.5//E

Elevation: 278m above sea level.

Lithology Description: The basal part of the outcrop section is marked by dark grey fissile shale of about 0.9m thick. Overlaying this bed is a parallel laminated silty clay of about 0.3m thick. This is overlain by a medium to coarse-grained, moderately sorted and friable sandstone. This bed consists of trough Cross bed, bioturbated by Ophiomorpha Spp and about 1m thick. This bed is successively overlain by another medium to coarse grained planar cross bedded, well sorted sandstone bioturbated by ophiomorpha Spp. The axis of the cross bed is aligned with clay drape and the bed has a thickness of about 1m. Directly above this bed in another bed consisting of fine to medium-rained, planar cross bedded and well sorted sandstone having a thickness of 0.5m. following this bed is another bed of sandstone that ranges from very coarse to granule in size, indurated with bioturbation of Ophiomorpha Spp. The sandstone bed has a thickness of 1.5m. Above this bed is overlain by medium to coarse-grained, moderately sorted sandstone with a thickness of about 0.5m. This bed is overlain by a wave-laminated, very coarse to pebbly clayey sandstone having a thickness of about 0.5m. This bed is followed by a clast supported conglomeratic sandstone with a thickness of about 0.5m. This bed is overlain by an indurated clayey sandstone characterized by trough cross bed, the grain ranges from medium to coarse in size and has a thickness of about 0.5m. Succeeding this bed is another bed consisting of medium to coarse-grained sandstone that is reddish brown in colour, planar cross beds with a thickness of about 1m. This bed is overlain by fine to coarse-grained clayey sandstone of about 1.4m thick. The sandstones are poorly sorted, with presence of planar cross beds and bioturbated by Ophiomorpha Spp. Directly above this bed is overlain by parallel laminated sand dominated heterolith with siltstone, reddish brown in colour. Thickness of the sand increases upward. The bed has a thickness of about 2.4m, bring the total thickness of the beds of the outcrop section to 12m.

Figure 3: Outcrop Section of Nkporo Formation at the axis Awgu-Mmaku Road showing the lateral view and the various rock units (the human scale is 157cm)

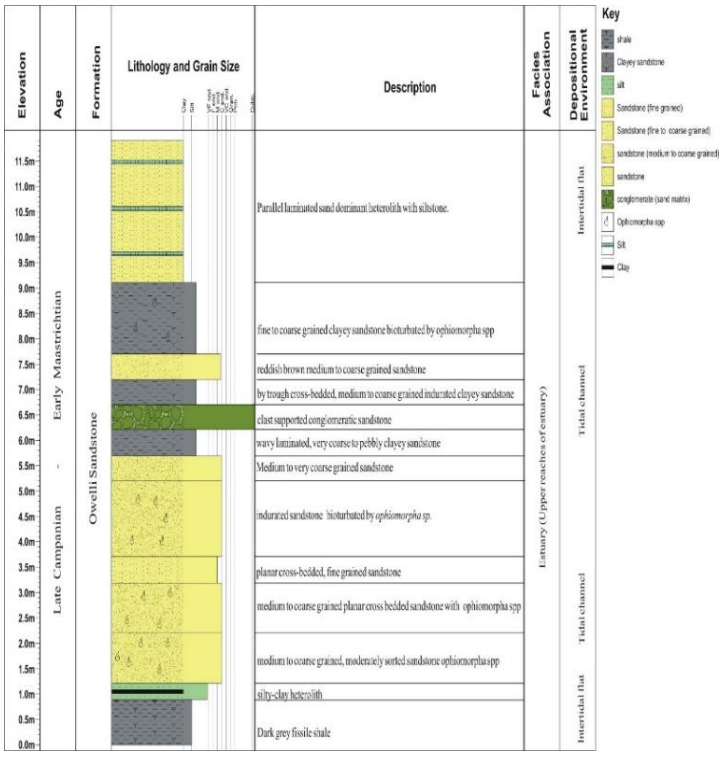

Figure 4: Lithologic Section of Nkporo Formation at the axis of Awgu-Mmaku Road

6.2 Petrography of the Campanian-Maastrichtian sediments.

Table 1: Point count percentage of the sample component

L1	Components	Point Count	% count
	Quartz	80	88.9
	Feldspar	8	8.9
	Rock fragments	2	2.2
	Total	90	100
L2	Components	Point Count	% count
	Quartz	60	85.7
	Feldspar	9	12.9
	Rock fragments	1	1.4
	Total	70	100
L3	Components	Point Count	% count
	Quartz	70	84.3
	Feldspar	7	8.4
	Rock fragments	6	7.3
	Total	83	100
L4	Components	Point Count	% count
	Quartz	50	79.4
	Feldspar	7	11.1
	Rock fragments	6	9.5
	Total	63	100

Generally, the QFL ternary plot framework composition of the Owelli sandstone were constructed using the detrital framework composition of the Owelli sandstone- quartz, Feldspar and lithic rock fragment. From the QFL plot, results show the classification of Owelli Sandstone as arkosic quartz arenites with average modal composition of Q, F, L (Petijohn, 1975; Quasim et al., 2017).

6.3 Mineralogical Composition

Quartz: Quartz being the most abundant mineral from the analysis is composed of 41% - 81% in the modal composition. Also present in the Owelli Sandstone are the Monocrystalline and polycrystalline quartz. Polycrystalline prevail over the monocrystalline quartz. The monocrystalline quartz occurs and varies from 85 – 305 of the total quartz content.

Feldspar: Feldspar occurrence in the Owelli sandstone varies from point to point across the Formation with 8% at the basal part of the Formation, 6% - 9% relatively above the basal part of the Formation. K-feldspars are more relatively abundant in the Owelli Sandstone than the plagioclase feldspars.

Lithic Fragment: Lithic fragment occurs a cluster of multiple grains that are represented by metamorphic, volcanic clastic and non-clastic lithic fragments (Quasim et al., 2017). An average of lithic clasts occurs in the Owelli sandstone. Sedimentary lithic fragments are common and consist of claystone, siltstone, and limestone fragments. Metamorphic lithic fragment is limited to quartzite and schist and consist of less than 3% of the lithic fragment composition (Ekwenye et al., 2015).

Cement: The major cement type found in the Owelli sandstone are the Calcareous (Calcite) cement type with a composition in the range of 10% - 40% across the Formation (from basal to the top of the Formation). The calcite cement occurs as mosaic of the interlocking crystals filling the pore spaces.

Table 2: Lithologic description and petrographic description of the Owelli sandstone

Location	Lithologic description	Petrographic description
L1	Coarse grained, light coloured, unconsolidated sandstone.	Microscopic studies show: quartz (80%), feldspar (8%), calcite as cement (10%), and rock fragment (2%). The grains are angular to sub-rounded, moderately to well sorted and compacted.
L2	Fine – medium grained, light coloured, slightly weathered, friable Sandstone.	Microscopic studies show: quartz (60%), feldspar (9%), calcite as cement (30%), and rock fragment (1%). The grains are sub-rounded to rounded, moderately to poorly sorted and compacted.
L3	Medium – coarse grained, light brown coloured, slightly weathered, friable Sandstone.	Microscopic studies show: quartz (70%), feldspar (7%), calcite as cement (17%), and rock fragment (6%). The grains are sub-rounded to rounded, moderately to well sorted and compacted.
L4	Fine – medium grained, light coloured, slightly weathered, friable Sandstone.	Microscopic studies show: quartz (50%), feldspar (6%), calcite as cement (40%), and rock fragment (3%). The grains are sub-rounded to rounded, moderately to poorly sorted and compacted.

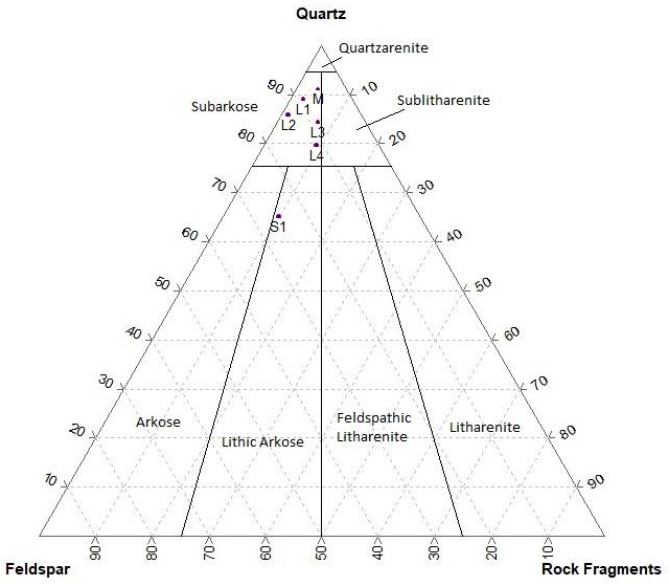

Figure 5: Composition of the Petrographic analysis of the Owelli Sandstone of the Nkporo Group that is plotted on a QFL (Q – quartz,F – feldspar,L – lithic fragment) diagram (after Pettijohn, 1975).

7. Discussion

The percentage of the K-feldspars present in the sediment reveals that the sediments source was not from a granitic rock owing to the fact that granitic rocks predominantly consist of composition that is more than 30% K-feldspars but were to be derivative of tormalites, quartz-diorites or granodiorites. The polycrystalline quartz identified are derivative of green schist facie metamorphic rocks. The rock fragments indicate that the source from which the sediments were derived are low grade metamorphic rock of Quartz-Biotite-Schist, as well as mafic volcanic rock which are the reason for the finer fraction of the rock. Also the ternary plot framework composition suggested a plutonic humid paleocurrent in the depositional environment.

7.1 Heavy Minerals Analysis

Heavy minerals are accessory minerals in sediments with specific gravity greater than 2.85. they are useful indicators of provenance, paleogeography and depositional processes operating at the time of sediment deposition. Under polarized light, heavy mineral species recognised include the non-opaque minerals (Zircon, Tourmaline, Rutile, Staurite, Gernet, Hornblende, Epidote) and opaque minerals. The heavy opaque minerals exceed the non-opeque minerals. The large amount of heavy opaque minerals suggested an aerated environment of deposition. Detrital heavy minerals are characteristics of source rock type (Petijohn, 1975). The heavy mineral assemblages which are garnet, epitode and staurolite suggested medium-grade metamorphic source rock whereas tourmaline, rutile and zircon indicates recycled sedimentary source, igneous and metamorphic source rock. More so, the Owelli sandstone is said to be mature. This deduction arises from the average value obtained from ZTR index data which is in the average range of 67%

Table 3: Results of heavy mineral analysis

Sample S/N	Sample	OPaque	Zircon	Tourmaline	Rutile	Staurlite	Garnet	Hornblende	Epidote	Non-Opaque	ZTR Index
1	L1	28	6	8	7	5	2	1	2	28	75%
2	L2	34	5	5	5	3	1	2	1	31	49%
3	L3	32	9	7	4	6	1	2	1	22	91%
4	L4	30	4	6	6	4	1	1	1	30	53%

8. Conclusion

From the petrographic analysis and data obtained, heavy mineral assemblages indicated that the sediments were derived from different sources thereby indicating a mixed provenance that supplied sediments to the Anambra Basin. The source is believed to be from a metamorphic rock, plutonic rocks and also a recycled sedimentary rock. The rounded, euhedral and sub-euhedral crystal nature of the heavy minerals such as zircon and tourmaline is a suggestive of recycled sedimentary rock and plutonic rock. Generally, the provenance study indicates that the Owelli sandstone are derived from recycled sedimentary rocks believed to have come from the Abakaliki uplift in the Benue Trough and the metamorphic and plutonic rocks that comes from the Oban Massif Basement Complex.

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