

Palynology and petrographical composition of Agbani sandstone and its environs

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ABSTRACT: This study examined semi-unconsolidated surface outcrop samples from three different localities within the Agwu Formations of the Lower Benue Trough (SE Nigeria). This paper focuses on the palynology, petrographic composition and depositional conditions of the three areas by using Quartz, Feldspar and Lithics (QFL system) petrography, including quartz ratios, and palynology. The composition of the Agwu samples is similar to that of the Agbani samples. Lithologic description showed that some sections of the outcrops were ferruginized and calcareous. The sandstone samples from both locations are characterised by a high content of quartz group, ranging from 46 to 95%. The prevailing mineral from this group is calcite (31%–65%), which is indicative of a low degree of the litification of organic matter. Relatively low contents of feldspar are very minimal (not exceeding 9%) and rock fragments (not exceeding 8%) were also determined and palynomorphs were poor. The content of minerals is inferred from microscopic studies and is variable but generally high, varying from 35 to 75%, similar to that of other formations within the study area; it consists mostly of quartz, calcite and clay minerals. This input of mineral matter is probably related to periodic inundations of mangrove swamps which reflect the influence of oxidizing conditions during deposition. The age prediction of the palynomorphs was indeterminate.

Keywords: Agwu Formations, Benue Trough, deposition, palynomorphs, mangrove swamp.

INTRODUCTION

The knowledge of petrography and palynological study of the Agbani sandstone is important to evaluate a close relationship between the origin, and the composition (mineralogical and biological) of its type section at Awgu, in Enugu State. The Agbani sandstone in a lateral equivalent of the Awgu Formation, which has been studied by several authors. The spatial differentiation of the various lithostratigraphic units in the sedimentary basins has not been substantially achieved but is somewhat tricky as a result of widely spaced outcrop and insufficient subcrop data (Nwajide and Reijers, 1996; Obaje *et al.*, 2004; Onyekuru and Iwuagwu, 2010). Several works have predicted the existence of oil and gas in the Campanian to Maastrichtian strata of the Anambra Basins. The basins are, however, still considered frontier basins due to the challenges associated with the interpretation of stratigraphy and structure arising from the non-availability

of subsurface data. It is a NE-SW trending sandstone body which is difficult to trace and map laterally due to poor exposures. It is estimated to be 40 km long and 10 km wide with an exposed thickness of 30-50 m. It is thickest at the type section at Eneagu–Amuri where a-50 m- thick exposure occurs. The member is composed of basal siltstone and coarse-grained cross-bedded upper sandstone with occasional pebble beds. The basal deposit is a transitional facies and consists of light–grey siltstone and shale. It is occasionally, marked by sparsely fossiliferous silty limestone which decreases upwards to predominantly fine-grained glauconitic sandstone with minor mottled shale laminated overlain by cross-bedded medium to coarse-grained sandstone.

Palynology can be rightly viewed as a tool used in the assessment of sediments to determine their age, paleoenvironmental history, and depositional origin. It

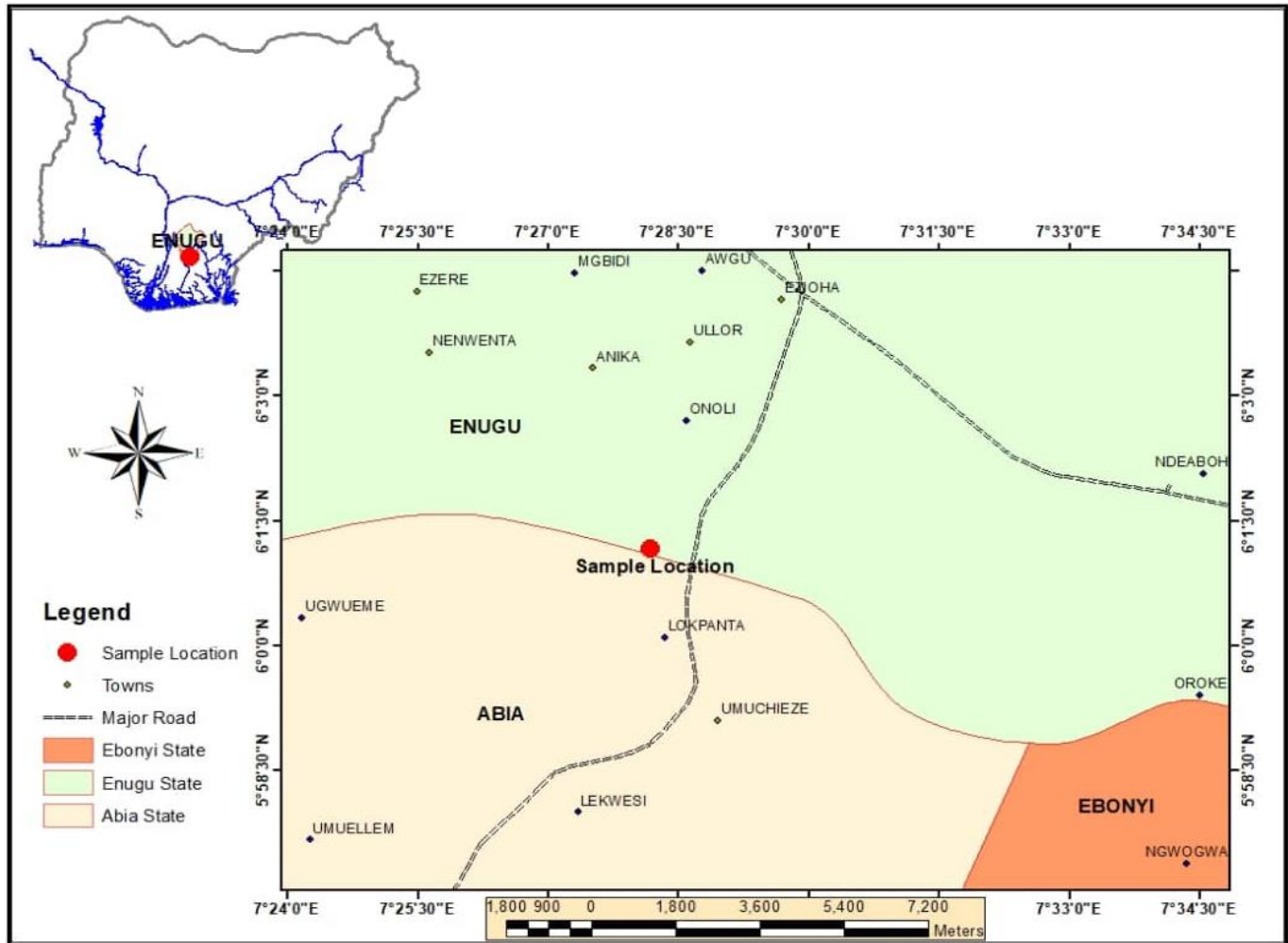


Figure 1. Map of the study area showing sample point.

makes use of plant-generated remains, such as spores and pollen. Biostratigraphic information regarding the formation is rare and is solely provided by a few published academic research works. Therefore, the aim of this paper is to determine the petrographic and palynological composition of Agbani sandstone in Agwu formations, (Figure 1). Petrographic indices, ratios and diagrams, were widely applied to the samples in order to determine the depositional history.

Geological setting of the Benue Trough

The Benue Trough can be described as a linear basin which trends northeast-southwest, with a length of 800 km and a width of 90 km, in the eastern part of Nigeria. The basin's origin is traced to an aulacogen which occurred on the Precambrian shield due to the separation of the American and African plates in the early Cretaceous period (Onyekuru and Iwuagwu 2010). The recorded sequence of events which led to the formation of the

Benue Trough is well documented (Burke *et al.* 1972; Benkhelil 1989). The Benue Trough has been subdivided into three segments that include Upper, Middle and Lower Benue Trough (Obaje *et al.*, 2004). The down-faulting of the Anambra Platform to the west of the Abakaliki Benue Trough formed the Anambra Basin (Umeji, 2007). These segments are however not delineated from each other by any concrete line. There are however records of the major localities which make up the depocenters of the different segments (Upper, Middle, Lower) (Petters, 1978).

The Late Cretaceous stratigraphic succession in the basins began with the Campanian - Maastrichtian Nkporo Shale and its lateral equivalent: the Enugu Shale and Owelli Sandstone. These basal units are overlain successively by the Early-Middle Maastrichtian Mamu Formation (Lower Coal Measures), the Middle Maastrichtian Ajali Sandstone and the Nsukka Formation (Upper Coal Measures) which was deposited from the Late Maastrichtian into the Danian (Murat, 1972; Obi *et al.*, 2001). The Southern Benue Trough (SBT) can also be described as the southwestern portion of an intracratonic

sedimentary feature (aulacogen) trending NE-SW, which extends from the Niger Delta Basin region towards the Chad Basin and into the regions of Niger and Chad Republics (Benkhelil *et al.*, 1989). The facies of the Benue Trough are known to have been deposited in a non-conformable manner upon the crystalline Basement Complex within this section of the trough, and occur within the range of longitudes 7°30' and 8°0'E and latitudes 6°0' and 6°30'N. The lithologic units which were deposited range from the Asu River Group (Middle-Late Albian) which occurs at the base of the section, to the Enugu Formation (Campanian-Maastrichtian) which is the overlying strata, with a marine, Cretaceous origin (Murat, 1972; Petters, 1980).

Sedimentology and stratigraphy

The history of sedimentation, of the Lower Benue Trough bears close relations to the evolution of the Lower Benue Trough, being also usually associated with the separation of the Gondwana supercontinental mass during the Middle Cretaceous (Obi *et al.*, 2001).

The trend of the evolution, of the Benue Trough is marginalized by the eastward migration of depocenters (Knoll, 1996). The initial depocenter earlier occurred within the Abakaliki Trough, from the Aptian to Santonian of the Cretaceous Period. In any case, recent studies have indicated that this active sedimentation has not been solely restricted to the Abakaliki Anticlinorium, rather has also occurred within the fault black graben of the structurally dynamic areas of the Benue Trough (Oloto, 2009). The pre-Santonian formations include the Asu River Group, the Eze Aku Formation, as well as the Awgu Formation. In any case, it has been indicated, that the Benue Trough experienced dynamic changes following the Santonian tectonic event, after which the area grew tectonically active (Obi *et al.*, 2001). The Benue Trough itself commenced its progradation by the deposition of deltaic facies. It subsequently subsided, and this was followed by the development of an east-west prograding system. The deltaic system was annihilated in the Maastrichtian as a result of the beginning of a major episode of marine transgression (Murat, 1972). The Nkporo Shale as well as the Lower Coal Measures which overlie it, were all deposited in the direction of the basin center.

In the tertiary, sedimentation occurred with the deposition of the Imo Shale Formation (Paleocene), the Ameki Shale (Eocene), the Ogwashi-Asaba (Miocene to Pliocene), and at last, the Benin Formation (Obi *et al.*, 2001). The stratigraphy of the southeastern Nigerian sedimentary basins (Table 1) has been described in terms of three main tectono-sedimentary cycles. The regional stratigraphic framework of the area also indicates that the Nkporo Formation basically constitutes the lithostratigraphic basal unit of the Afikpo basin. Post-deformational

cycles of sedimentation in the Lower Benue Trough led to the formation of the Campanian-Maastrichtian paralic and marine shales of the Nkporo and Enugu Formations, which are overlain by the Mamu Formation coal measures. The fluviodeltaic sandstones of the Owelli and Ajali Formations both overlie the Mamu Formation and comprise its lateral equivalents in most areas.

The Nkporo and Enugu Shales represent the grey marsh and pro-delta fossiliferous facies of the Late Campanian-Early Maastrichtian sedimentation phase (Odigi, 2012). The accumulation of the sediments of the Enugu/Nkporo Formations basically reflects a funnel-shaped, and shallow marine depositional setting which graded into low-energy channel marshes. The Mamu coal-bearing Formation and the Ajali Sandstone both accumulated in this epoch of regressive sedimentation of the Nkporo cycle (Okoro *et al.*, 2020). The Mamu Formation basically takes the form of a narrow depositional strip which trends north-south from the Calabar Flank and extends westward around the area of the Ankpa Plateau and terminates at Idah, close to the River Niger. The Ajali Sandstone is representative of the maximum level of regression at a period during which the coastline had a concave geometry. Tectonic factors influenced the sedimentation and can be recognised in the tidal sand waves that are characteristic of the Ajali Sandstone. The Imo Shale and Nsukka Formations indicate the commencement of another phase of transgression within the Lower Benue Trough in the Paleocene. These shales comprise significant amounts of organic matter and may constitute a potential hydrocarbon source in the northern segment of the Niger Delta region (Reijers *et al.*, 1997).

MATERIALS AND METHODS

The samples were collected from two different surface outcrops, each approximately 5 m thick and consisting of thin beds separated by intercalation of clastic materials (Figure 2). The samples were not assigned a specific level; they were collected perpendicular to the bedding of the Agbani sandstone within the Agwu formations (Figures 1 and 2).

Field technique

Reconnaissance and detailed field studies were carried out at the site. The field relationship between the rock unit and selected exposures was given close attention. The study of rocks in hand specimens in the study outcrop provided a good basis for tentative identification of the rock samples using their mineral constituent, texture, and structures. General structure patterns and tectonic behaviour were also studied in the different outcrops within the study area. Samples were collected at different locations at the quarry pit for thin section and petrographic analysis.

Depth	Lithology and Grain Size										Description
	Clay	Silt	VF snd	F snd	M snd	C snd	VC snd	Gran.	Peb.	Cobb.	
L1S15	[Lithology bar for L1S15]										Sandy Clay, brownish, slightly calcareous
L1S14	[Lithology bar for L1S14]										Clayey Sand, reddish, non-calcareous
L1S13	[Lithology bar for L1S13]										Sandy Clay, brownish, non-calcareous
L1S12	[Lithology bar for L1S12, highlighted in green]										Silt, yellowish, non-calculus and woody
L1S11	[Lithology bar for L1S11]										Clayey Sand, reddish, slightly calcareous
L1S10	[Lithology bar for L1S10]										Clayey Sand, reddish, slightly calcareous
L1S9	[Lithology bar for L1S9]										Clayey Sand, reddish, slightly calcareous
L1S8	[Lithology bar for L1S8]										Milkish brown, slightly calcareous silty clay
L1S7	[Lithology bar for L1S7]										Yellowish, slightly calcareous Sandy Clay
L1S6	[Lithology bar for L1S6]										Clay, slightly calcareous and reddish
L1S5	[Lithology bar for L1S5]										Clayey Sand, reddish, slightly -calcareous
L1S4	[Lithology bar for L1S4]										Clayey Sand, reddish, slightly -calcareous
L1S3	[Lithology bar for L1S3]										Yellowish, slightly calcareous Sandy Clay
L1S2	[Lithology bar for L1S2]										Yellowish, slightly calcareous Clayey Sand
L1S1	[Lithology bar for L1S1]										Whitish, non-calcareous Silty Clay

Figure 2. General lithologic log of the study area.

Laboratory technique

Laboratory work involves the preparation of thin sections (horizontal and vertical sections) from the rock samples obtained from the field. The thin section was examined with the help of a photomicrograph to ascertain the mineral compositions of the different rock samples. Thin sections are important because they provide undisturbed sectional samples of the rock that are not only effective for rapid identification of the common minerals present but are also particularly adapted for the study of their spatial relations and grain size, texture and structure. Five of the 10 samples were analyzed by point counting for the palynological studies. The number of species counted ranged from 25 to 143 and the counting results were converted into percentages.

RESULTS AND DISCUSSION

Microscopic studies reveal that the petrographic distribution of the samples is relatively constant and the concentration of quartz is similar throughout the sections in (Table 2), with respect to petrographic composition. The sandstone samples contain high percentages of quartz (Figure 3), ranging from 35 to 75%. The lithologic

description in Figure 2 shows sandy clay to clayey sand, very yellowish to brown, and non-calcareous. The grains are fine to coarse, sub-angular to sub-rounded, poorly sorted and compacted. Comparative analysis showed that pollen grains constituted the lowest counts, followed by spore particles and dinoflagellates (Table 1). Absolute palynomorph counts across the study area are given in the distribution table.

Palynology

The palynological properties of the samples from the Agbani Formation are briefly described. Ten samples were collected from these localities. However, only six were productive with respect to palynomorph content. These samples may be classified as follows: samples S1, S3, S4, S11, S12 and S13 belong to the Oligocene coal zone (Agbani Formation). Selected palynomorphs are illustrated in Figure 3. The Oligocene coal samples (S1, S3, S4, S11, S12 and S13) are rich in angiosperms; however, spores and gymnosperms are rarely seen. Among the angiosperms, *Diatom sp*, *Acrostichum aureum*, *Laevigatosporites discordatus*, *Verrucatosporites alienus* and *Verrucatosporites alienus* occur in low quantities (Table 2). *Diatom sp* reaches its maximum value (100%)

Table 1. The absolute occurrence and distribution of the palynomorph counts in the examined samples.

Palynomorphs species sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
<i>Diatom sp</i>	2	-	3	5	-	-	-	-	-	-	-	-	-	-	-
<i>Verrucatosporites alienus</i>	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Laevigatosporites discordatus</i>	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
<i>Acrostichum aureum</i>	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<i>Dinocyst indeterminate</i>	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
<i>Communitated fungal hyphae</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
<i>Diatom sp</i>	-	-	-	-	-	-	-	-	-	-	-	1	2	-	-

Table 2. Showing percentage of mineral composition in samples: Dott's classification based on composition and proportion of grains.

Sample ID	Components	Point count	% count
S1	Quartz	47	77
	Feldspar	11	18
	Rock fragments	3	5
	Total	61	100
S2	Quartz	72	91
	Feldspar	5	6
	Rock fragments	2	3
	Total	79	100
S3	Quartz	78	95
	Feldspar	3	4
	Rock fragments	1	1
	Total	82	100

in sample S3. *Laevigatosporites discordatus* reaches a peak abundance of 20% in sample S4. The percentages of *Acrostichum aureum* are about 14.2% and absences in S2, S5, S6, S7, S8, S9, S10, S14 and S15. In sample S11, the presence of communitated fungal hyphae with a peak abundance of 100% was the only occurrence in the study area. Sample S4 shows that the pollen of *Dinocyst indeterminate* occurs in minor quantities.

Though the pollen and spores defined from the Agbani formation indicate a broad range over the geologic age inference in this study, based on the palynomorphs which have been analyzed indicated to be Campanian-Mastrichtian, which is Late Cretaceous.

In these cases, eight types of dispersed organic matter and palynomorphs were identified. These include spores and pollens, fungal remains, freshwater algae, micro foraminiferal inner linings, structured phytoclasts (wood, cuticles and parenchyma), and unstructured phytoclasts (comminuted and degraded fragments). Sporomorphs identified in the samples include *Levigatosporites discordatus*, *Longapertites maginatus*, *Foveotriletes margaritae*, *Cycadopites sp.*, *Ephedripites regularis*, *Gleicherudites senonicus*, *Foveodrites margaritae*,

Leiotrites adriennis, *Retidiporites sp*, *Cingulattisporite ornatus*, *Psilatricolpites sp* and *Ariadnaesporites spinus*. Freshwater species include Azollacretacea and Dinoflagellate indeterminate. Marine dinoflagellates include *Spiniferites sp* (Figure 4).

Petrographic data

There are several indices and diagrams based on mineral ratios (Obiora *et al*, 2005). In this study, among these indices and diagrams, is ABC ternary diagrams applied to the sandstone samples. At Agbani, the Sandstone is made up of heterolithic and large cross bedded facies (Figures 5 and 6). Represent the photomicrographs from Agbani. Samples taken from the heterolithic beds which indicate that the fine quartz grains are generally subangular to angular. They are moderately to poorly sorted layers with pebble grains in places. The large pebble grains are subrounded and show clear grain margins. Stress zones and fracture lines are not common on these grains. The surfaces of the grains are smooth with no etching. Most of the quartz grains are monocrystalline showing straight

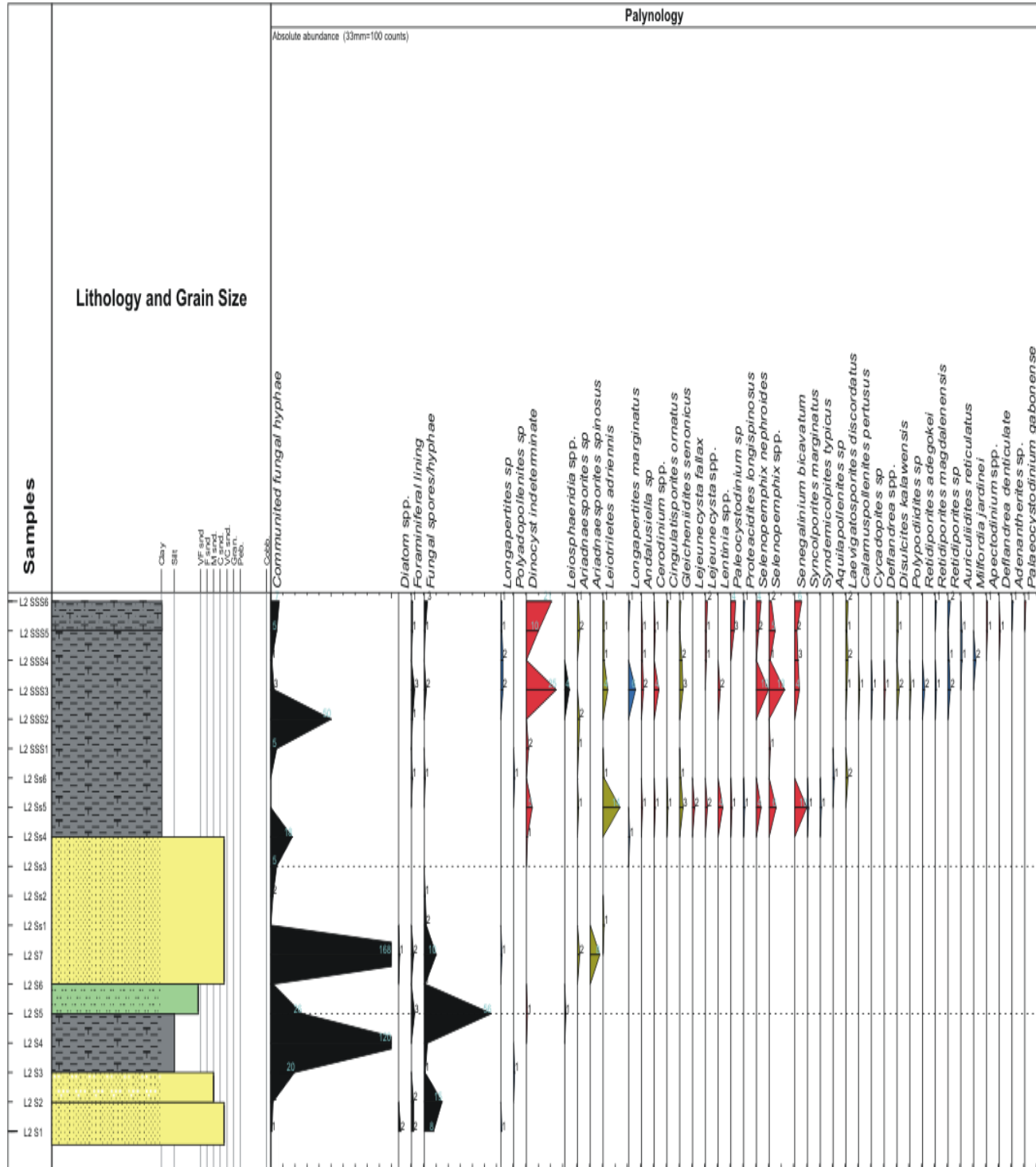


Figure 3. Showing distribution chart of total palynomorphs recovery from the study area.

margins. The iron oxide coating is seen on some of the grains, the mineral glauconite occurs with the presence of inclusions. In between each of the beds are thin mud rapes with an average of about 5 cm in thickness. These beds contain fine grain with so much fracture lines, alteration and corrosion of grain margins. Most of the surfaces are

etched. The iron oxide coating is very common coat on the quartz grains. The cross bedded facies of the Sandstone in Agbani are also subangular to angular, moderately to poorly sorted beds. They show monocrystalline and polycrystalline quartz grains. Authigenic quartz is seen as quartz overgrowth in Figures 5 and 6. Most of the grain

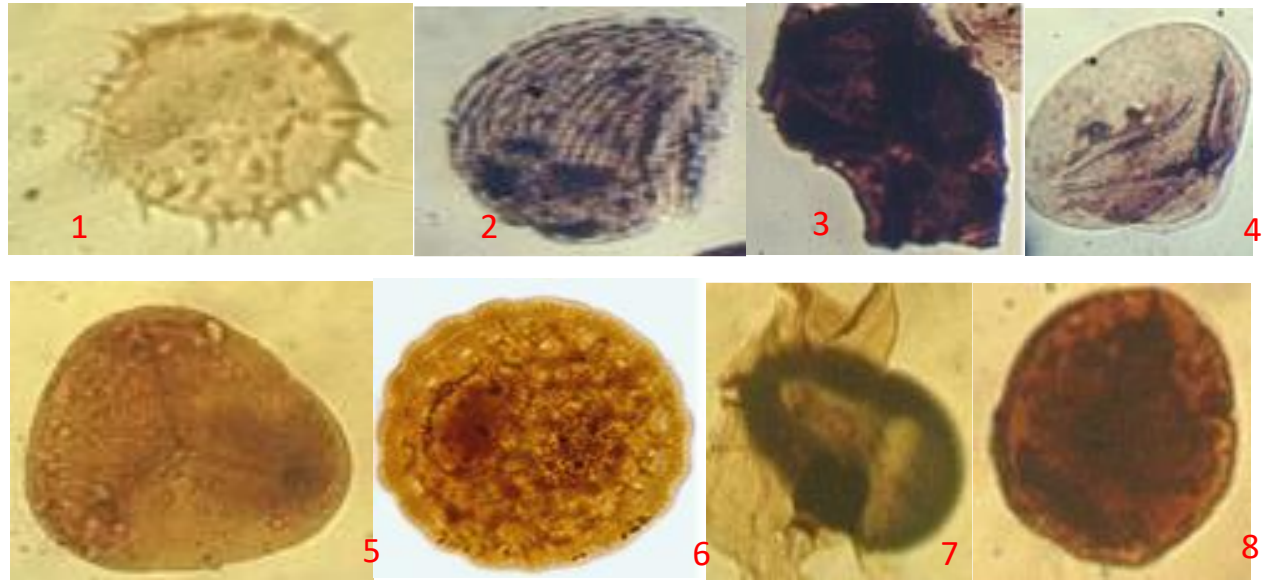


Figure 4. Photomicrographs of palynomorphs in the study area: 1. *Spiniferites*, 2 *Cicatricosisporite*, 3. *Lygodiosporites perverrucatus*, 4. *Glaeicheniidites senonicus*, 5. *Tricolporopollenites sp*, 6 *Polyadopollenites sp*, 7 *Inner chitinous linings*, 8 *Monocolpopollenites sphaeroidites*.

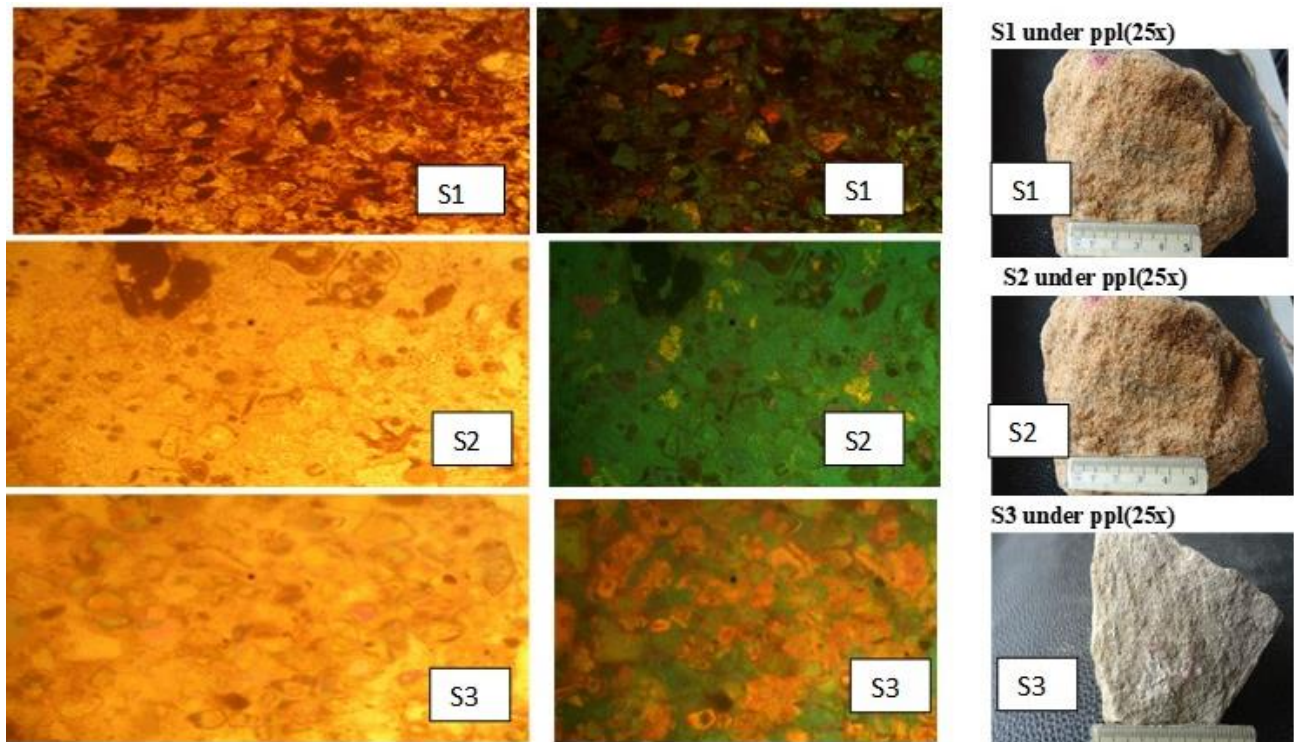


Figure 5. QUARTZITE: Samples 1-3 are originally composed of tightly interlocking grains, with granoblastic textures of quartz and a little feldspar (De Swardt, 1953). It appears quite similar to sandstone, and the best way to tell the difference is to break both the rocks, while sandstone shatters into many grains, quartzite breaks across the grains. Quartzite forms in two different ways. In the first way, under the high pressures and temperatures of deep burial, sandstone or chert recrystallizes resulting in a metamorphic rock. A quartzite in which all traces of the original grains and sedimentary structures are erased may also be called metaquartzite. A quartzite that preserves some sedimentary features is best described as a metasandstone or metachert (Harper, 1993). The second way involves sandstone at low pressures and temperatures, where circulating fluids fill the spaces between sand grains with silica cement. This kind of quartzite, also called orthoquartzite, is considered a sedimentary rock, not a metamorphic rock because the original mineral grains are still there and bedding planes and other sedimentary structures are still evident (Iloeje, 1975). The grain size is about 1.2cm.

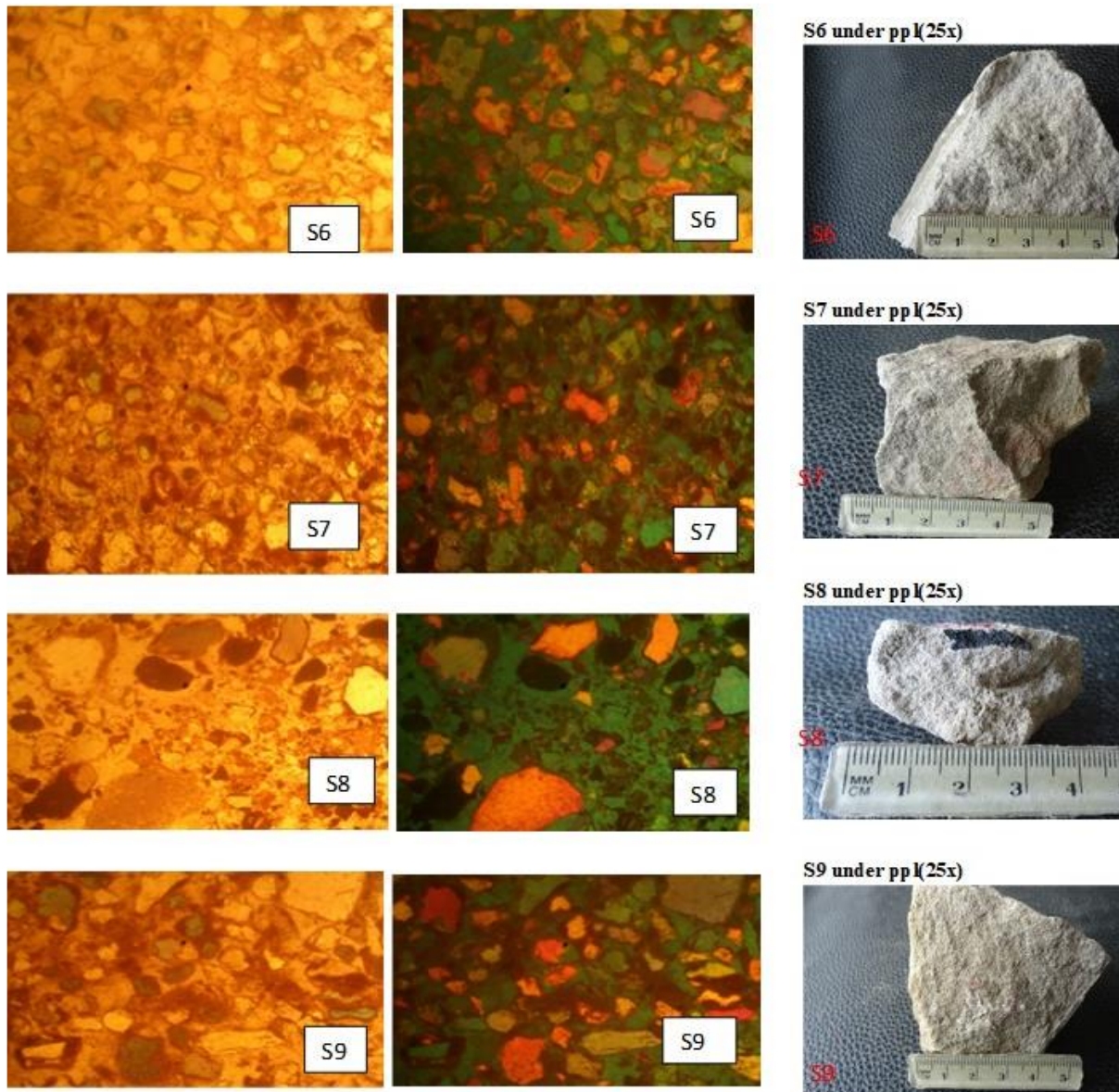


Figure 6. Quartz (40%), feldspar (1%), calcite as cement (56%), and rock fragment (3%). The grains are fine to coarse, poorly sorted and angular to sub-rounded in shape is about 2-3mm also contains alternating bands of light quartzo-feldspathic minerals and dark ferromagnesian minerals mica.

margins show alteration and corrosion along grain margins and fracture lines. Stress zones and shadows were also noticed on the grains.

The petrographic examination of thin sections reveals a great deal of information about the depositional and diagenetic history of any sediment. The dominant mineral of the Sandstone is quartz, which is above 95% of the composition of the sediment. The occurrence of feldspar is very minimal. The Sandstone shows great compositional maturity. The Sandstone is poorly sorted to moderately sorted with subangular to angular grains, which implies textural immaturity. The subangular to angular grains indicate they have not travelled far distance. Smaller

quartz grains form the matrix of the Sandstone and cementing material is almost nonexistent due to the diagenetic effects, though quartz overgrowth occurs in places. This has contributed to the friability of the Sandstone. Most of the grains have straight or tangential contacts. The quartz grains show one generation of quartz overgrowth, indicating one cycle of sedimentation. Monocrystalline and polycrystalline quartz occur, with the monocrystalline predominant. Some of the grains of the polycrystalline quartz are polygonal with straight simple boundaries, while a few have sutured contacts. Elongated and subspherical quartz occur. Some of the quartz grains display acicular and irregular inclusions, characteristic of

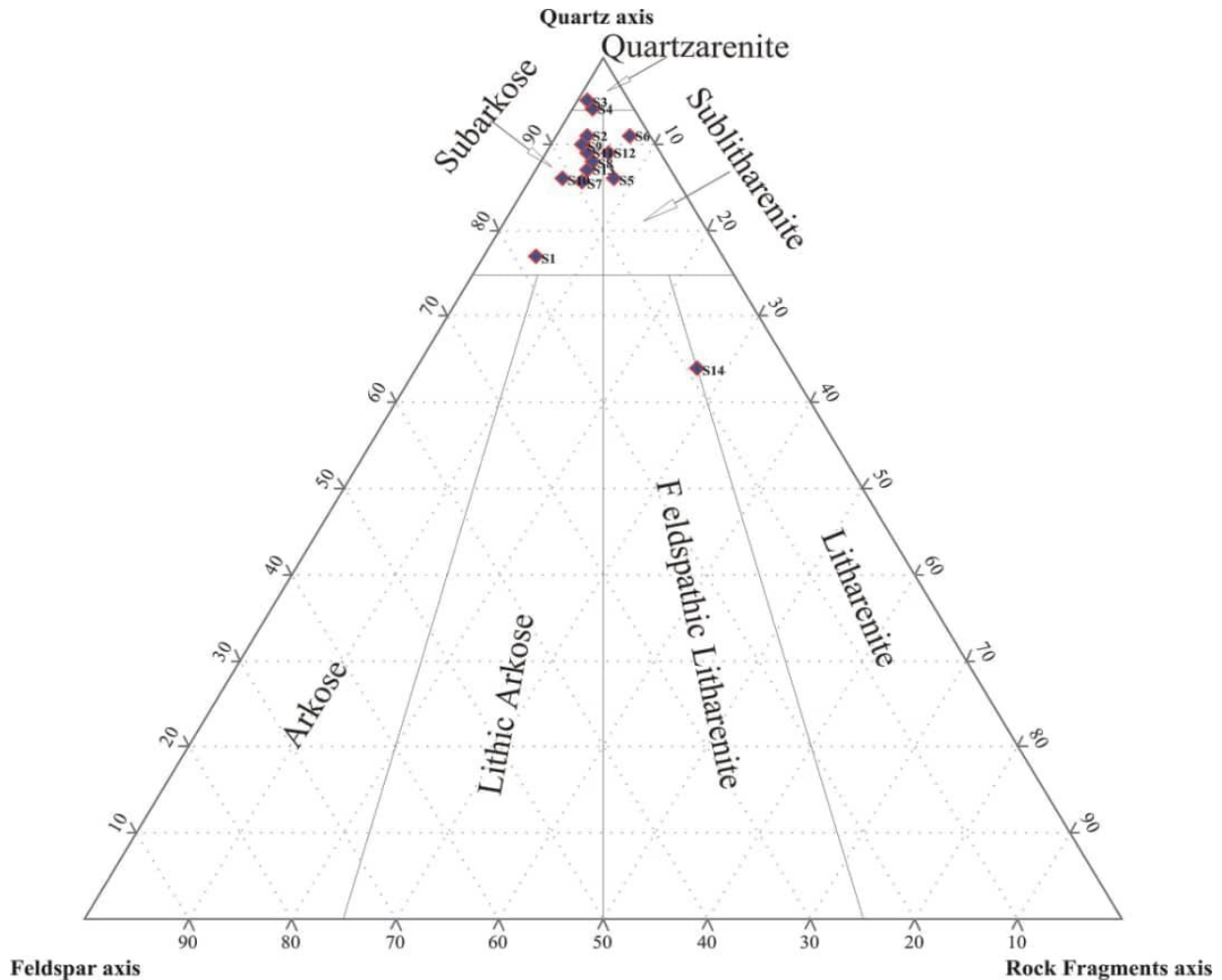


Figure 7. Plot of Quartz Feldspar Lithics (QFL system) Triangle sandstones from this study on a compositional triangle for sandstone classification (after Folk 1980).

igneous rock. The QFL diagram or QFL Triangle in Figure 7 is a type of ternary diagram that shows compositional data from sandstones and modern sands, points counted using Robert Folk's classification scale. The diagram reveals that the samples collected from Awgu town in Enugu State are classified into Subarkose Sandstone. Sandstone is a rock comprised mostly of minerals formed from sand. The stone gains its formation through centuries of deposits forming in lakes, rivers, or on the ocean floor. These elements group together with the minerals quartz or calcite and compress. In time, the sandstone is formed by the pressure of these minerals coming together.

Composition of source rocks

The clastic grains that provide the most information in this regard are quartz, feldspars and rock fragments. Quartz: Quartz grains usually bear clues as to their source. According to Blatt (1992), quartz grains derived from gneissic rocks are polycrystalline and are commonly

composed of more than five crystals. The polycrystalline grains dominate in the S1 to S3 and S6 to S9 sandstone units (Figure 3) and consist of five to seven crystals, having sutured boundaries indicating a metamorphic source rock. The samples representing all the lithologic units showed a higher proportion of undulose quartz grains. The significance of this with respect to the provenance is not very clear since no real difference exists in the degree of undulosity in quartz from igneous and metamorphic rocks (1-10). Folk (1980) however thinks strong undulosity is a characteristic feature of quartz grains from gneisses and schist. Feldspar: Potash and sodic feldspars which were observed in the studied samples may equally be derived from gneissic and granitic sources. K-feldspars are associated with gneissic sources and plagioclase with granitic sources (Table 2). The feldspar grains may have been derived from polygenetic sources since the two types of feldspars were represented in the samples. The major fact that emerges from the analysis is that the source area is a basement complex containing perhaps all these rock types in various proportions with the metamorphic rock

type appearing to dominate the region.

Age determination

Assignment of age to the sediments from the study area was based on the selected key age diagnostic taxa based on the stratigraphic chart of Petters (1982) (Table 1), and the recognized palynomorphs taxa that connote Campanian age, according to Umeji and Edet (2008) includes *Cingulatisporite ornatus*, *Gleicheniidites senonicus*, *Leiotritites adrennis*, *Laevigatosporite sp*, *Cyathidites australis*. Based on the sporomorph assemblage of *Foeveotritetes magaritae*, *Zivisporites blanesis*, *Longapertites marginatus*, *Retridiporites magdaliensis* and *Monocolpites marginatus* typical of the Late Cretaceous of West Africa-South America phytogeographic province (Herngreen and Chlonova, 1981) and the assemblage of Umeji and Edet (2011) mentioned above which are typical of the study area, the sediments were thus dated Late Campanian to Late Maastrichtian.

Conclusion

The palynology and petrographic composition of the Agbani sandstone section at Awgu, in the Enugu area of Southeastern Nigeria was analysed. The study was based on field and laboratory studies, including sedimentological, thin section petrographic and palynological analyses carried out with a view to determine the origin of the sediments and characterise them with polymorphs recovered. The sedimentary structures and composition were also useful to infer the origin of the sediments and also predict the age and depositional environment as well as geologic history, of the outcrop based on the recovered polymorphs and the petrographic consisting of five to seven crystals, having sutured boundaries indicating a metamorphic source rock. Age determination of the sediments from the study area was based on the selected age diagnostic taxa indicating Late Campanian to Late Maastrichtian.

CONFLICT OF INTEREST

The authors declare they have no conflict of interest.

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