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DEPOSITIONAL FRAMEWORK AND STRATIGRAPHY OF THE KONSHISHA AREA, SOUTHERN BENUE TROUGH

OKWUDIRI ALOYSIUS ANYIAM, LILIAN CHIAMAKA ONUORAH AND IKENNA CHRISTOPHER OKWARA

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ABSTRACT

The study focuses on the stratigraphic succession and depositional environment in areas around Konshisha, southern Benue Trough. The area is underlain by the Ezeaku Formation and Konshisha River Group. Integrated outcrop, textural and petrographic analysis aided inference of the depositional framework of sediments in the area. Three lithofacies were identified – micaceous sandstone (Facies A), limestone (Facies B), and grey shale (Facies C). Textural analysis indicated that the sandstones are fine grained with mean size ranging from 2.2 to 2.8 phi, very poorly to poorly sorted and deposited in a fluvially-influenced shallow marine setting. Petrographic analysis of the sandstone showed that the sediments have undergone compaction as a result of tectonic stress, shown by the elongate shape of some quartz grains, dominant line contact, and the tilted nature of the beds. Sandstones are both compositionally and texturally sub-mature, implying a proximal source. Results from the petrographic analysis of the limestones reveal micrite as the dominant matrix, with skeletal fragments, pelloids, recrystallized bivalve shells and some mineral grains (quartz and muscovite) present. The depositional environment is probably lagoonal, evidenced by the fine lamination of the limestone beds and low diversity. This study suggests an initial transgressive phase in the Turonian, with the deposition of the grey shale and limestone facies in a shelf – lagoonal setting, and a subsequent regressive phase that led to the deposition of micaceous, ripple-laminated sandstones in a fluvially-influenced shallow marine environment.

KEYWORDS: Stratigraphy, petrography, facies, depositional environment, Turonian

INTRODUCTION

The Benue Trough is a linear, northeast-trending depression in the eastern part of Nigeria. Recently, many researches have been on the Benue Trough mainly because of the basin's mineral potentials and interesting geological features. Because of the basin's prospect for hydrocarbons and solid minerals, there is need for proper documentation of its stratigraphy and depositional framework. The diversity in rock lithology and stratigraphic heterogeneity occur as a result of many different depositional environments in which they are deposited (Nichols, 2009). These environments include fluvial, lacustrine, deltaic, shallow marine and deep marine settings. The study area lies between latitude 07^0 00^{1}N and 07^0 05^{1}N and longitude 08^0 35^{1}E and 08^0 40^{1}E and covers towns like Tse-Agberagba, Aba, Mbashima, Mbawar, Dio-Mbatwer, Kuilav-Mbatwer, Azem and Mbazegav (Fig. 1). This study therefore, focuses on the reconstruction of depositional framework of the lithologic successions observed in areas around Konshisha, southern Benue Trough, which has been hitherto unreported.

Okwudiri Aloysius Anyiam, Department of Geology, University of Nigeria, Nsukka, Nigeria.
Lilian Chiamaka Onuorah, Department of Geology, University of Nigeria, Nsukka, Nigeria.
Ikenna Christopher Okwara, Department of Geology, University of Nigeria, Nsukka, Nigeria.

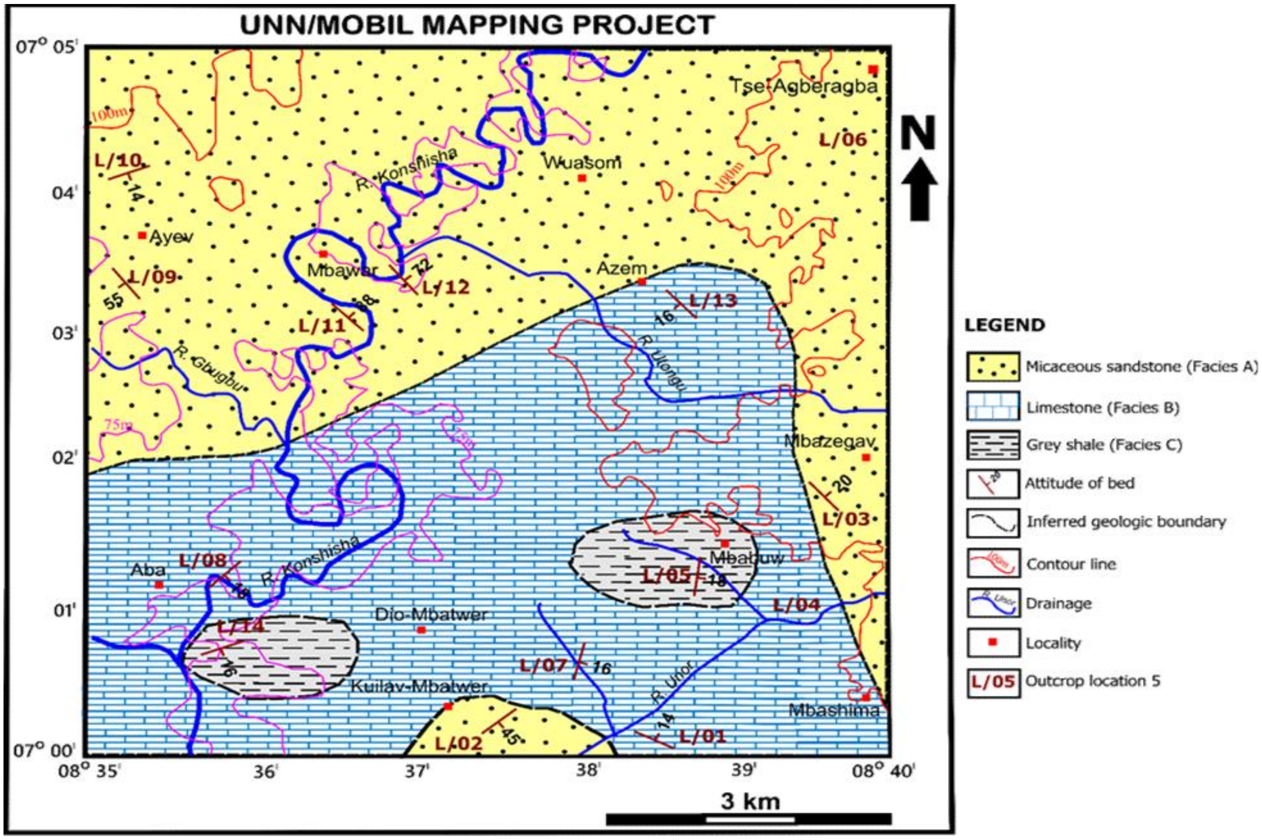


Figure 1: Lithofacies map of the study area showing various localities and rivers

1. Geologic Setting and Stratigraphy of the Southern Benue Trough

The Benue Trough of Nigeria is a rift basin in central West Africa that extends NNE–SSW for about 800 km in length and 150 km in width (Obaje, 2009). The southern limit is the northern boundary of the Niger Delta, while the northern limit is the southern boundary of the Chad Basin. The Trough contains up to 6,000 m of Cretaceous sediments of which those predating the mid-Santonian have been compressionally folded, faulted, and uplifted in several places (Whiteman, 1982; Wright et al., 1985). Sedimentation in the southern to middle Benue Trough started with the marine Albian Arufu, Uomba, Gboko Formations, generally referred to as the Asu River Group (Offodile, 1976, Nwajide, 1990). The lithologic composition of the Group comprises mainly limestones, shales, micaceous siltstones, mudstones and clays (Offodile, 1976); and the average thickness is estimated to be about 1,800 m. These are overlain by the Cenomanian Keana and Awe Formations and the Turonian Ezeaku Formation (black shales, limestones and siltstones). The Keana Formation resulted from the Cenomanian regression which deposited fluvio-deltaic sediments and consists of cross-bedded, coarse grained feldspathic sandstones with occasional bands of shales and limestones. The Awe Formation is also deposited as transitional beds during the Late Albian – Early Cenomanian regression, comprising medium to coarse grained calcareous sandstones, carbonaceous shales and clays. The Ezeaku Formation is the lateral equivalent of Konshisha River Group and the Wadata Limestone in the Makurdi area. The deposition of Ezeaku Formation is attributed to the beginning of marine transgression in the Late Cenomanian. The sediments are made up of mainly of calcareous shales, micaceous fine to medium grained sandstones and beds of limestones which are in places shelly (Obaje, et al., 1999).The Coniacian coal-bearing Awgu Formation lies conformably on the Ezeaku Formation. In the Makurdi area, Makurdi Sandstone interfingers with the Awgu Formation. The mid-Santonian was a period of inversion (folding) throughout the Benue Trough. The Campano-Maastrichtian Lafia Formation ended the sedimentation in the middle Benue Trough, after which widespread volcanic activities took over in the Tertiary (Fig. 2). In the area covered by this study, only the Ezeaku Formation and Konshisha River Group are encountered as outcrops.

2. METHODS AND MATERIALS

The study involved the detailed description of lithologic units within the area and about fourteen outcrop locations were logged and sampled for petrographic and granulometric analyses. The coordinates of these locations were obtained using the Global Positioning System (GPS) device for reference purposes, and stratigraphic logs were generated at each outcrop location, using SedLog^{TM} 3.1. This was followed by detailed facies analysis to aid paleo-environmental interpretation. Additionally, samples of indurated sandstones and limestones were subjected to petrographic studies, while the fairly consolidated sands were further disintegrated for granulometric analysis. This was done in order to have a better understanding of the textural and compositional characteristics of the lithologic units, which were useful in the paleo-environmental interpretation of the area.

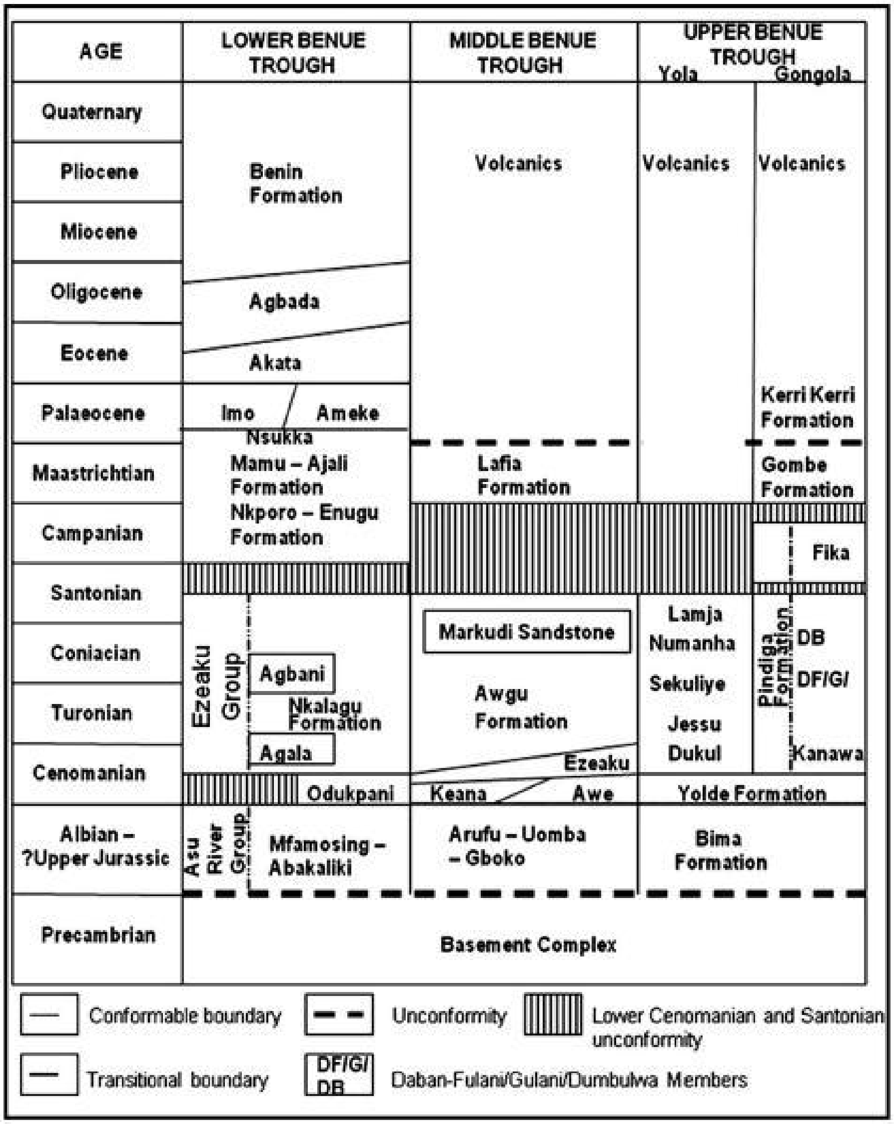


Figure 2: The stratigraphic correlation across the Benue Trough (Guiraud, 1990)

3. RESULTS AND DISCUSSION

3.1 LITHOFACIES ANALYSIS

The results show three distinguishable lithofacies based on lithology, colour, grain size, texture, bedding contacts and sedimentary structures. They are: (1) micaceous sandstone facies (Facies A); (2) limestone facies (Facies B); and (3) grey shale facies (Facies C). Facies A belongs to the Konshisha River Group while Facies B and C are sub-units of the Ezeaku Formation.

3.1.1 Micaceous sandstone facies (Facies A)

Description: This facies was encountered at seven locations in Ayev, Kuilav-Mbatwer, Mbazegav and Mbawar (Fig. 3) The outcrop at Ayev (Gbugbu stream) extended laterally for about 30 m and occurs as intercalated beds of fine-grained, micaceous, poorly to moderately sorted, indurated sandstones with ripple-laminated siltstone (Fig. 4e). The best of this exposure is 3.1 m thick, and typically very fine grained, well sorted, yellowish, micaceous, ripple laminated and well indurated. The laminae occur as 0.5 to 0.7 mm thick wavy laminae that are mostly symmetrical. Straight to sinuous ripple structures were also observed (Fig. 4a & d). In most parts, they are densely fractured and oriented in a NW-SE direction. The beds are generally tilted, dipping at high angles ranging from 45° to 88°. In other locations, they have rippled surfaces and show flaser bedding or shaly inclusions (Fig. 4c). They also occur intercalated with shales and have biogenic structures with a moderate to high bioturbation intensity (Fig. 4b). The facies is well developed along the Konshisha River section in Mbawar, with a lateral extent of about 35 m and thickness of 6.5 m.

Interpretation: The rippled and fine grained nature of this facies indicates a hydrodynamically lower flow regime, possibly in the lower reaches of a fluvial system (Miall, 1978). Sinuous ripples developed during relatively higher flow velocities, while flaser bedding results from draping of the trough of ripples, during "quiet" flow periods (Allen, 1968; Baas, 1999). The high angle dip is due to a compressive folding and uplift event, possibly in the Santonian (Nwajide, 1990).

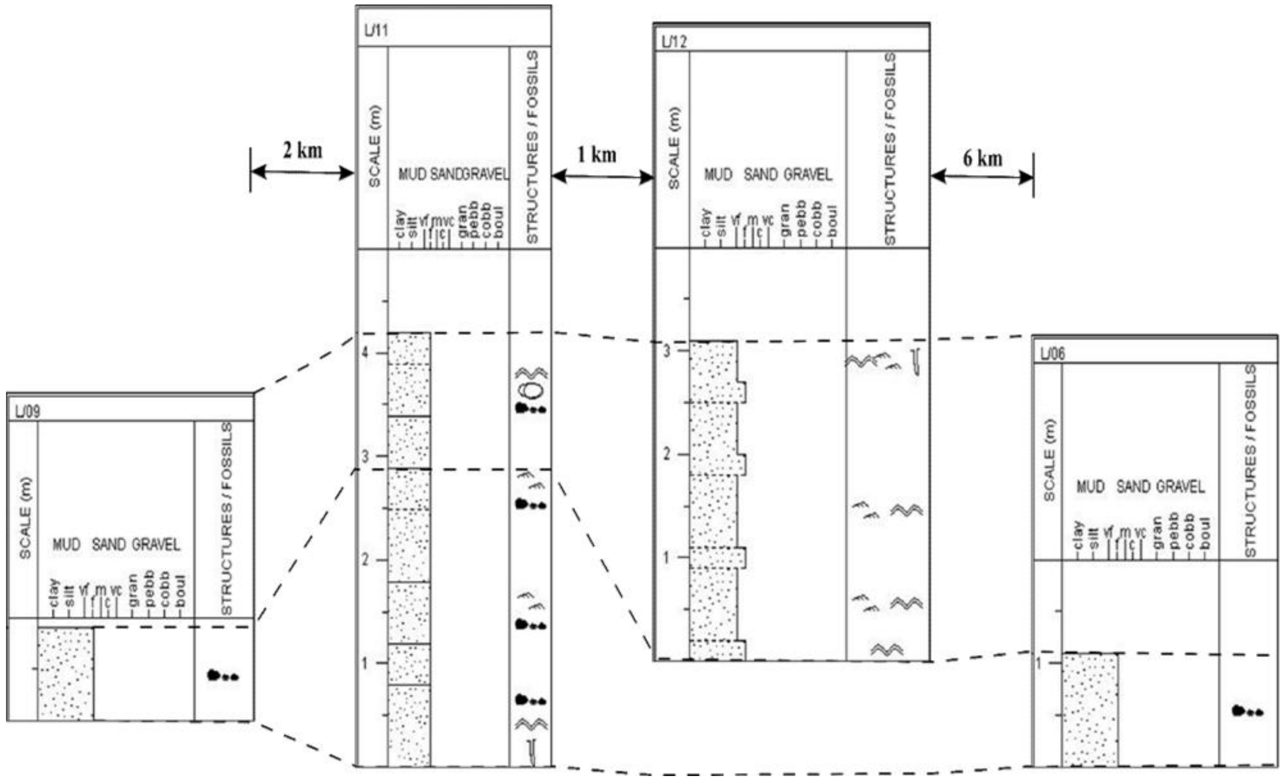


Figure 3: SW-NE “constant spacing” stratigraphic correlation panel for the micaceous sandstone facies (Facies A). See legend for symbols in figure 8b.

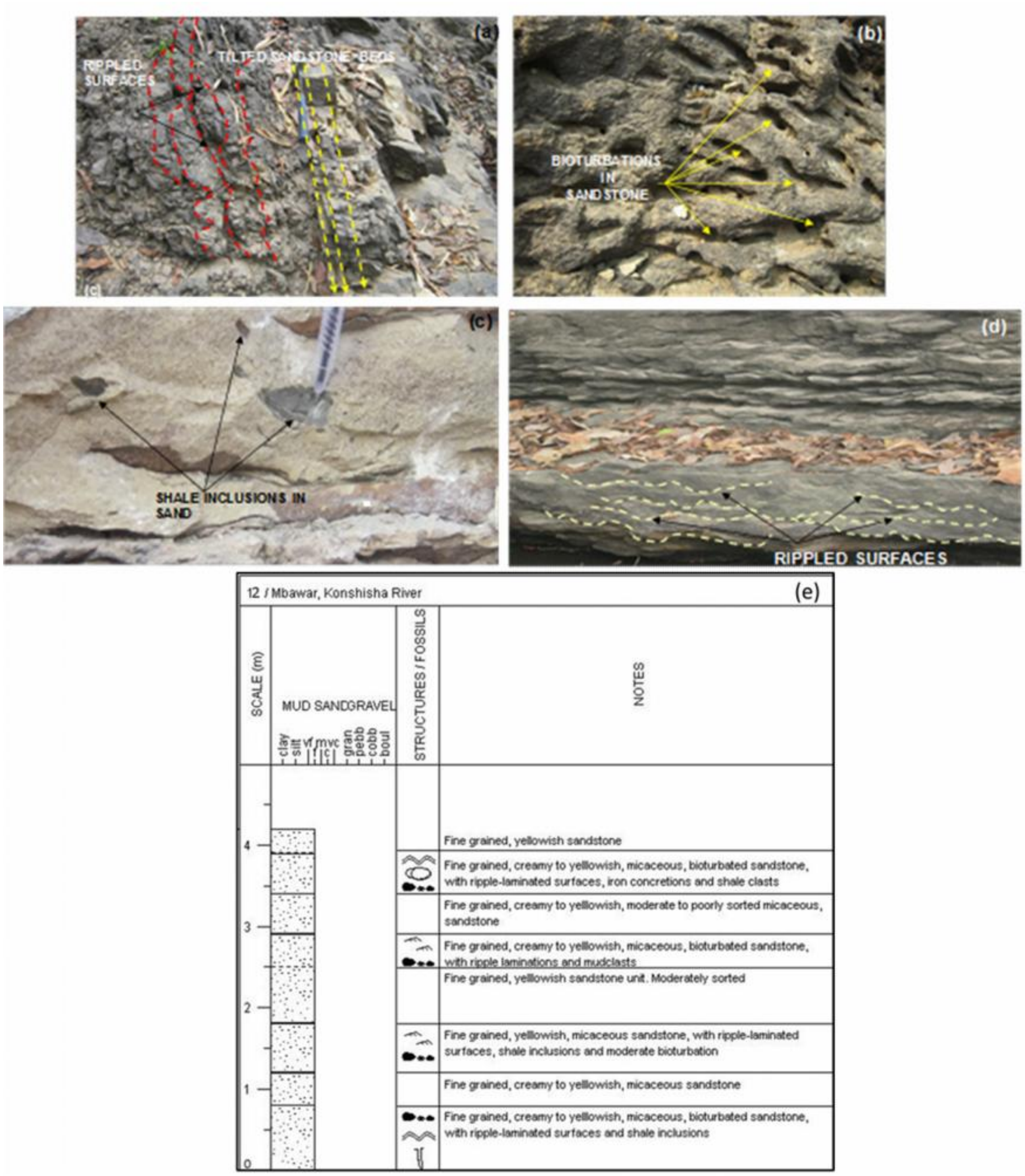


Figure 4: Field photographs of Facies A: (a) Tilted sandstone beds at L/11/Mbawar, Konshisha River (b) Closer view of bioturbated sandstone at L/11/Mbawar (c) closer view of shale inclusions on sandstone at L/11/Mbawar (d) ripple-laminated siltstone encountered at Gbugbu Stream in Ayev (e) Stratigraphic profile of L/12/Mbawar, Konshisha River section (See legend for symbols in figure 8b)

3.1.2 Limestone facies (Facies B)

Description: Facies B is very extensive and underlying nearly half the study area. It was encountered at five locations in Mbashima, Meelem Aba, and Azem (Fig. 5). In most parts, it appears grey, fine grained, highly indurated with fractures and fossiliferous (Fig. 6a-d). Intact and broken skeletal remains and impressions of ammonites of varying whorl sizes were observed (Fig. 6a). They are increasingly shaly towards the top and may have rippled surfaces. At its best exposure along Konshisha River in Meelem Aba, the base is a 1 m thick, fine grained, greyish, and highly indurated limestone with fossilized shells, which effervescences on addition of dilute acid. Overlying this unit is a 3.4 m dark grey, fine grained, indurated limestone, which has closely spaced, dense fracture network, trending in the NW-SE and NE-SW directions. Calcite precipitates have filled the fractures oriented in the NW-SE direction. This facies also occurs as repeated interbedding of fine grained, dark, fossiliferous, fractured, rippled, and highly indurated limestone; fine grained, dark grey, bioturbated, micaceous, highly indurated mudstone; and grey, fissile, fractured shale with calcareous nodules (Fig. 6c).

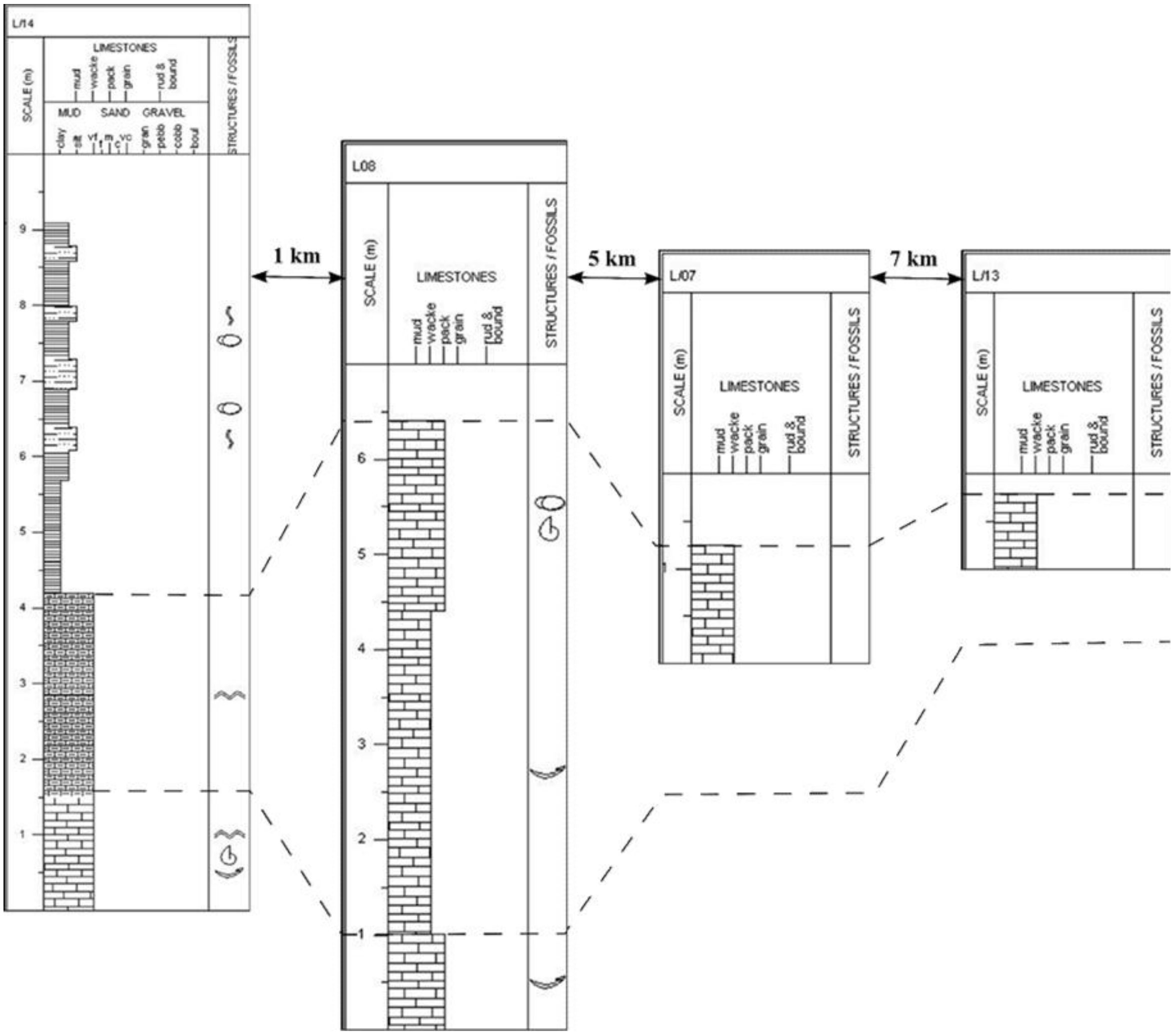


Figure 5: SW-NE "constant spacing" stratigraphic correlation panel for the limestone facies (Facies B). See legend for symbols in figure 8b.

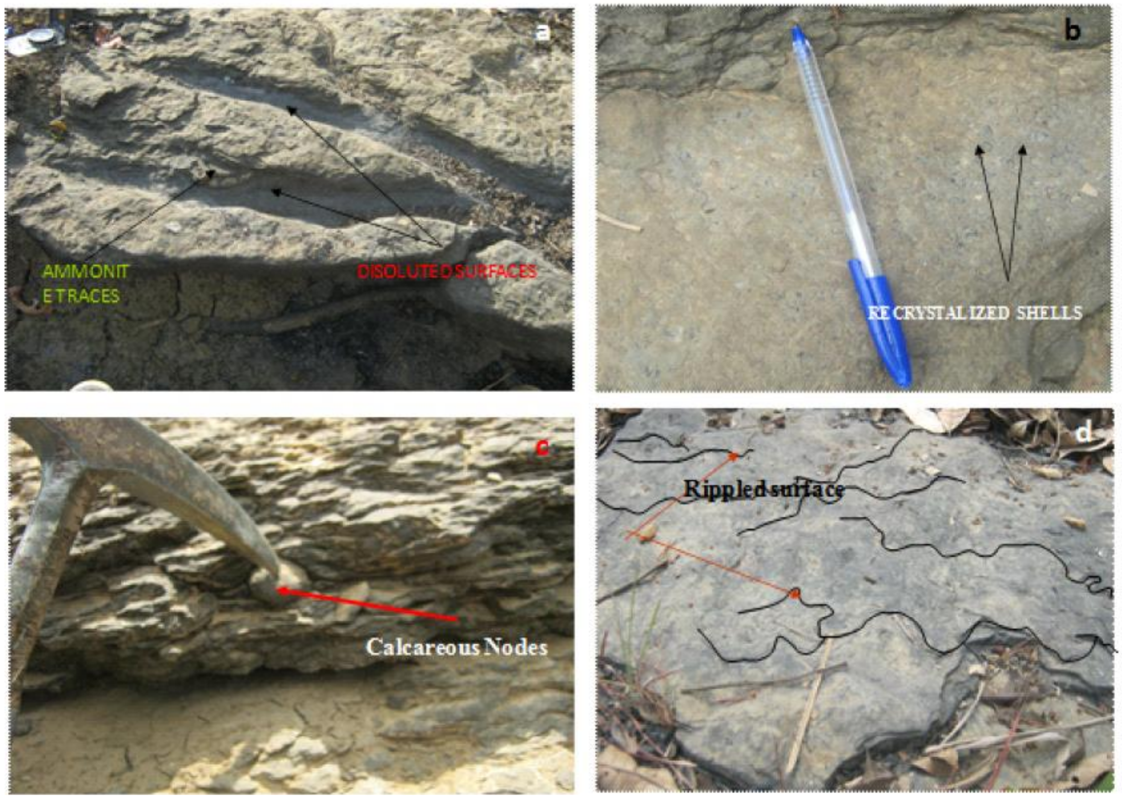


Figure 6: Field photographs of Facies B: (a) Limestone at L/01/Meelem with ammonite trace and dissolution surfaces (b) Limestone bed with fossilized shells at L/08/Meelem (scale: pen = 18cm) (c) Limestone bed with calcareous nodes at L/08. Note the "fissile-like" structure (scale: hammer = 33cm) (d) ripple-surface limestone at L/13/Azem

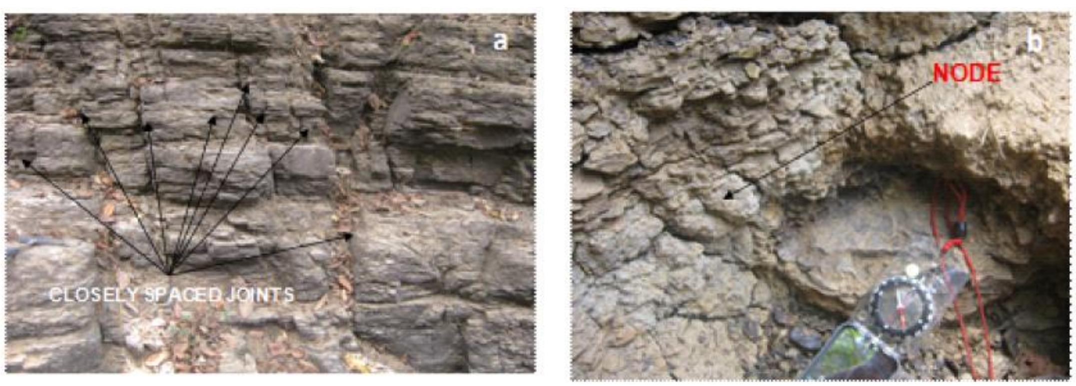


Figure 7: Field photographs of Facies C: (a) Fissile shale showing closely spaced joint set in L/08/Meelem (b) Grey shale at L/05/Mbabuw, Unor stream

Interpretation: The presence of a diverse species of shelled organisms (e.g. ammonites) suggests a marine environment. Broken shell fragments are probably due to the action of waves, which may also have led to the development of near symmetric ripples (Tucker, 2009). The highly indurated nature is a consequence of burial compaction and/or diagenetic cementation. The fractures are tectonic in origin, and those with calcite filling (NW-SE trend) probably formed earlier than those without (NE-SW trend).

3.1.3 Grey shale facies (Facies C)

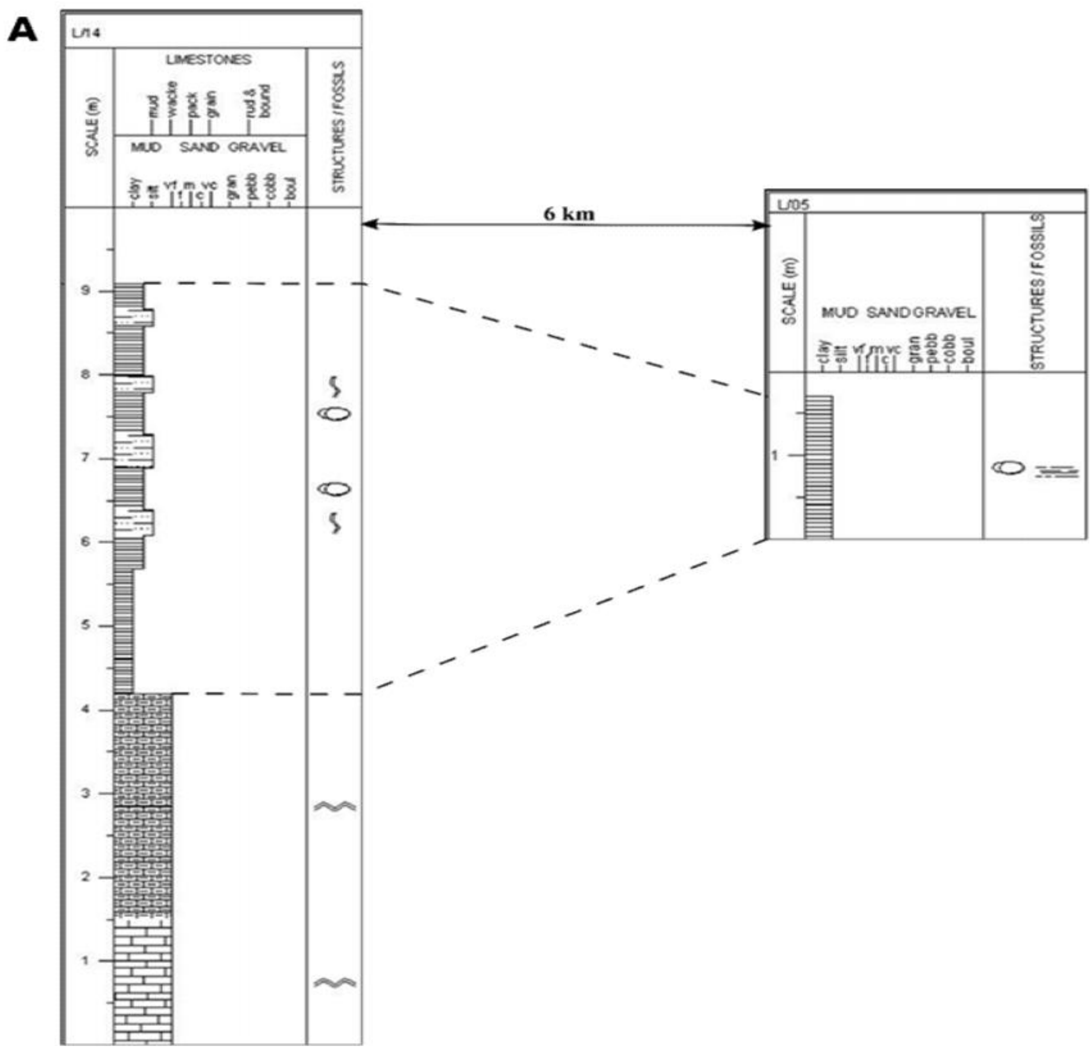
Description: Facies C conformably overlies Facies B, showing gradational contact passing from one facies to the other. It occurs as grey to black, usually fissile laminated shales with pyritic or calcareous nodules/concretions, thin interbedded siltier units, and closely spaced joints (Fig. 7a). Limestone clasts were observed within some shale units. This facies is usually highly weathered with vegetative cover and the best exposure was a 1.7 m thick shale section found at Ukor stream in Mbabuw (Fig. 7b; (Fig. 8).

Interpretation: The fissile nature indicate hemipelagic settling from suspension in a very low energy, anoxic setting, while the pyritic and calcareous concretions are diagenetic in origin. Rare storm episodes may have resulted in the resedimentation of limestone clasts observed.

3.2 Grain size analysis

Representative, fairly consolidated sandstone samples collected from Facies A were subjected to grain size (granulometric) analysis. The two-segment probability curve types suggest that the sands were transported by saltation and suspension mechanisms only (Fig. 9) (Visher, 1969). A summary of computed univariate grain size parameters and their interpretations (Folk, 1968) are shown in Table 1. Mean grain size ranged from 2.23 phi to 2.77 phi (fine sand), sorting ranged from 1.43 phi to 2.02 phi (poorly to very poorly sorted), skewness ranged from -0.32 phi to 0.12 phi (coarse skewed to fine skewed), while kurtosis ranged from 0.97 phi to 1.11 phi (mesokurtic). The sands are generally fine grained, poorly sorted, near symmetrically skewed and mesokurtic. Although the overall geologic significance of kurtosis is relatively unknown (Boggs, 2006), Akaegbobi and Boboye (1999) suggested that a mesokurtic nature implied sediments derived from multiple sources.

Bivariate parameter plots used in discriminating depositional environments (Miola and Weiser, 1968; Friedman, 1961) show that the sandstone samples are fluvially-derived (Fig. 10). Tthe results of the multivariate parameters analysis (Sahu, 1964) are that **Yu: shallow marine: fluvial** range from -17.033 to -11.017, indicating deposition in a fluvial environment (Table 2), whereas **Yu: beach: shallow marine** range from 151.2 to 194.8, indicating shallow marine deposition. In summary, the sandstones were deposited by low energy currents in a fluvially-influenced shallow marine environment. They are therefore, characteristically fine grained, poorly sorted and lack traction load (Fig. 9; Table 1)



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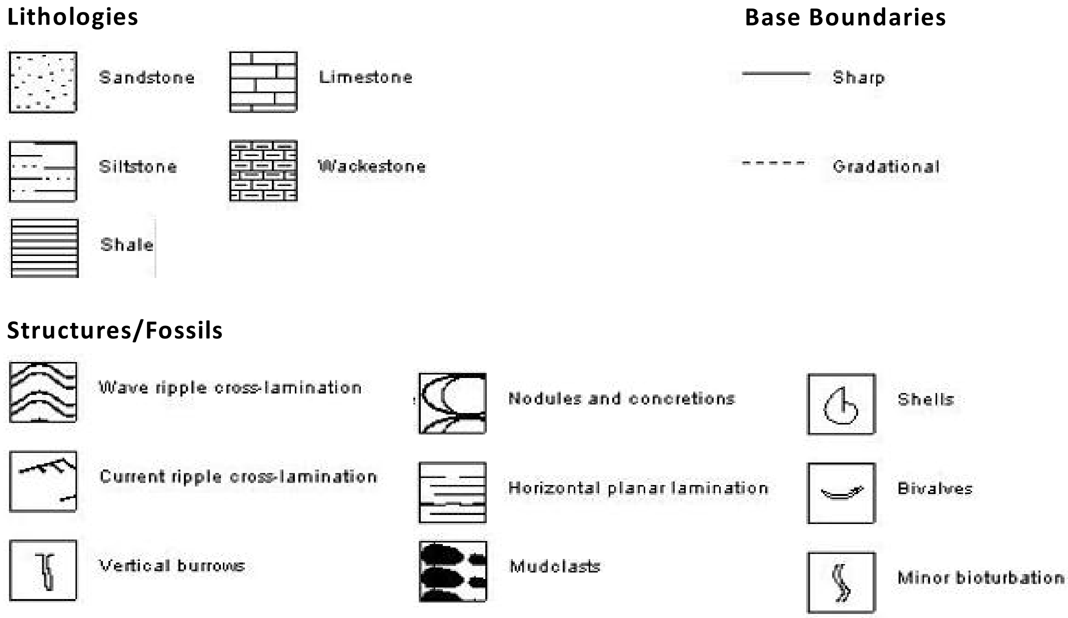

Figure 8: (a) SW-NE "constant spacing" stratigraphic correlation panel for the grey shale facies (Facies C); **(b)** Legend for symbols used in all the stratigraphic logs in this study

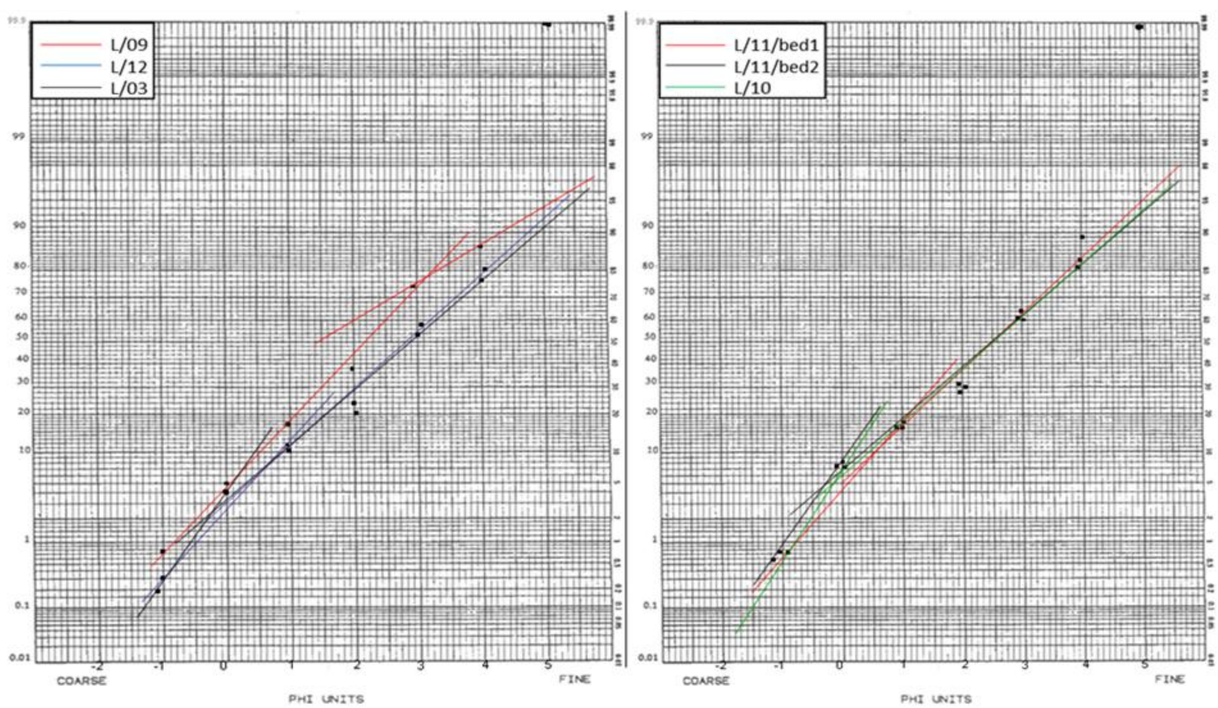

Figure 9: Log-probability plots of grain size data for sandstone samples derived from locations 3, 9, 10, 11, and 12 (after Visher, 1969). Two-segment curve show transportation by mainly saltation and suspension mechanisms

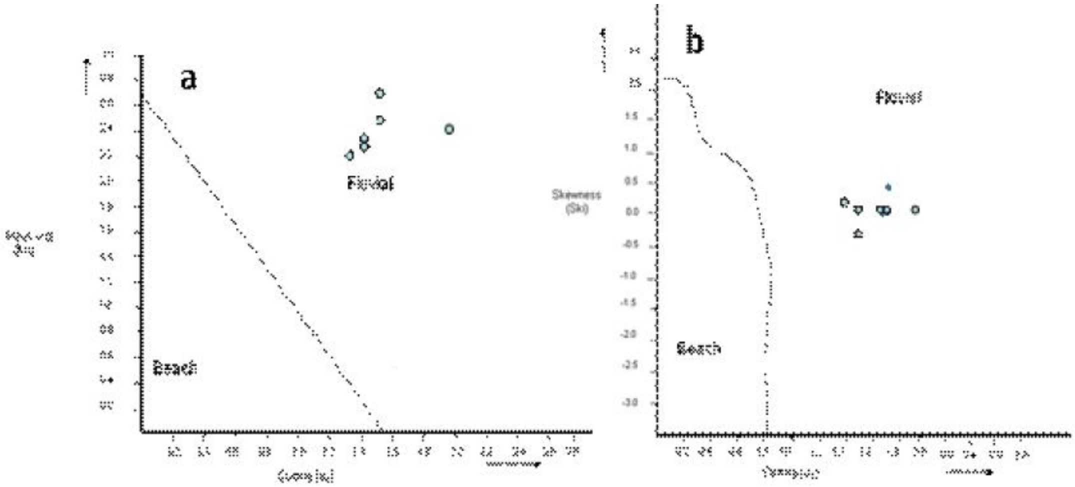

Figure 10: (a) Plot of mean size versus sorting (Miola and Weiser, 1968) (b) Plot of skewness versus sorting (Friedman, 1961)

Table 1: Table showing calculated univariate parameters and their interpretations

SAMPLE	MEAN SIZE	SORTING	SKEWNESS	KURTOSIS
L/09	2.23 (Fine sand)	1.435 (Poorly sorted)	0.119 (Positively skewed)	1.108 (Mesokurtic)
L/12	2.43 (Fine sand)	1.523 (Poorly sorted)	-0.324 (Negatively skewed)	0.972 (Mesokurtic)
L/11	2.55 (Fine sand)	1.643 (Poorly sorted)	0.0093 (Symmetrical)	1.006 (Mesokurtic)
L/11	2.53 (Fine sand)	2.017 (V. poorly sorted)	0.0263 (Symmetrical)	0.979 (Mesokurtic)
L/03	2.30 (Fine sand)	1.433 (Poorly sorted)	0.0098 (Symmetrical)	0.976 (Mesokurtic)
L/10	2.77 (Fine sand)	1.596 (Poorly sorted)	0.0362 (Symmetrical)	1.021 (Mesokurtic)

Table 2: Table showing the result of multivariate parameters and their interpretations

SAMPLE NO.	BEACH: SHALLOW MARINE (Yu-value and interpretation)	SHALLOW MARINE: FLUVIAL (Yu-value and interpretation)
L/09	154.71 (Shallow marine)	-12.462 (Fluvial)
L/12	153.27 (Shallow marine)	-11.017 (Fluvial)
L/11/2	169.96 (Shallow marine)	-13.665 (Fluvial)
L/11/1	194.80 (Shallow marine)	-17.033 (Fluvial)
L/03	151.24 (Shallow marine)	-11.895 (Fluvial)
L/10	170.89 (Shallow marine)	-13.316 (Fluvial)

3.3 Petrographic analysis

The representative limestone (Facies B) and sandstone (Facies A) samples were cut into thin sections and studied using a petrographic microscope. The limestone petrographic studies (Fig. 11) revealed that the major components of the limestone include allochems (grains), micrite (dark brown lime mud matrix) and sparite (clear cement precipitated in pores between grains). The allochems present are peloids and bioclasts (skeletal fragments). The bioclasts are mainly shell fragments of bivalves that have been filled by calcite through recrystallization. Based on the Folk (1962) scheme, the limestone in the area are classified as pelbiomicrite, biosparite, biomicsparite and biomicrite (Table 3). Based on the Dunham (1962) scheme, the limestones range from lime mudstone to wackestone, with occasional packestone. The intact nature of the shell fragments reflects an intrabasinal origin, suggesting fewer amounts of reworking and transport in a low energy setting (Tucker, 2009). Also, the presence of detrital silicate grains, such as quartz, in the limestones is suggestive of their proximity to shoreline. The limestones were probably deposited in a lagoonal environment, as evidenced by their finely laminated nature (Nichols, 2009).

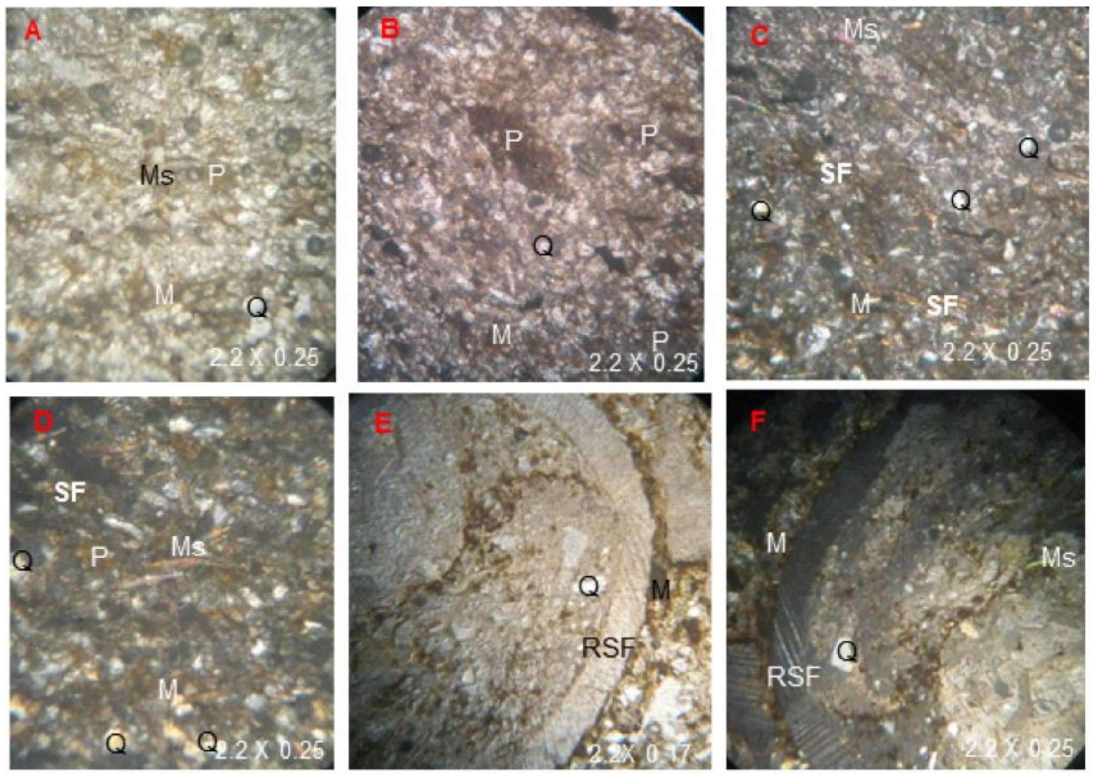

Figure 11: Photomicrographs of sample from L/07 (A), and L/08 (B-F). SF = skeletal fragments (bioclast); Ms = muscovite; P = pellets; Q = quartz; M = micrite; RSF = recrystallised shell fragment (bioclasts)

The sandstone petrographic studies (Fig. 12) revealed that the sandstones are fine-grained, moderately sorted, sub-angular sub-litharenites classified according to the Pettijohn (1975) scheme (Table 4). Its framework grains include quartz, feldspar, muscovite and rock fragments which make up nearly 90% of the rock, on average. Other components are clay-sized matrix, whose mineralogy is difficult to determine under the microscope; and re-precipitated quartz as cement. They make up about 10% of the rock, on average. There is a high ratio of polycrystalline to monocrystalline quartz, mostly showing undulose extinction. Line contacts are dominant but point and floating contacts were also observed. Compositionally, the sandstones are sub-mature with an average maturity index (ratio of quartz: feldspar + rock fragments) of 4.88. The preponderance of polycrystalline over monocrystalline quartz further suggests a low stage of maturity (Blatt, 1967). Texturally, the sandstones are also sub-mature, characteristically moderately to poorly sorted, and angular to sub-angular. This indicates less distance travelled, as well as less reworking. The elongate/lath-shaped form observed in some of the quartz grains may reflect the effect of basin tectonics during the sediment deposition (Tucker, 2009).

Table 3: Petrographic data of the Konshisha Group limestone samples showing percentage allochems, micrite and sparite composition

Sample no.	Composition of limestone (%)				Composition of allochems (%)				Folk (1962) scheme	Dunham (1962) scheme
	Allochem	Detrital grains	Matrix	Sparite	Bioclast	Ooids	Intraclast	Peloid		
L/07	57	6	34	3	35	0	5	60	Pelbiomicrite	Packstone
L/08-1	29	1	15	55	90	0	10	0	Biosparite	Wackestone
L/08-2	25	0	35	40	90	0	5	5	Biomicsparite	Wackestone
L/13	10	8	72	10	95	0	0	5	Biomicrite	Mudstone

Table 4: Petrographic data of the Konshisha Group sandstone samples, showing percentage detrital components normalised for quartz (Q), feldspar (F), and lithic/rock fragments (L). Qm = monocrystalline quartz; Qp = polycrystalline quartz

Sample no.	Qm	Qp	Q (Qm +Qp)	F	L	Qm:Qp	Q:(F+L)
L/10-1	25	60	85	6	9	0.42	5.67
L/10-4	24	56	80	12	8	0.43	4.00
L/11-5	14	72	86	8	6	0.19	6.14
L/11-2	15	60	75	15	10	0.25	3.00
L/9	22	67	89	9	2	0.33	8.09
Mean	20	63	83	10	7	0.32	4.88

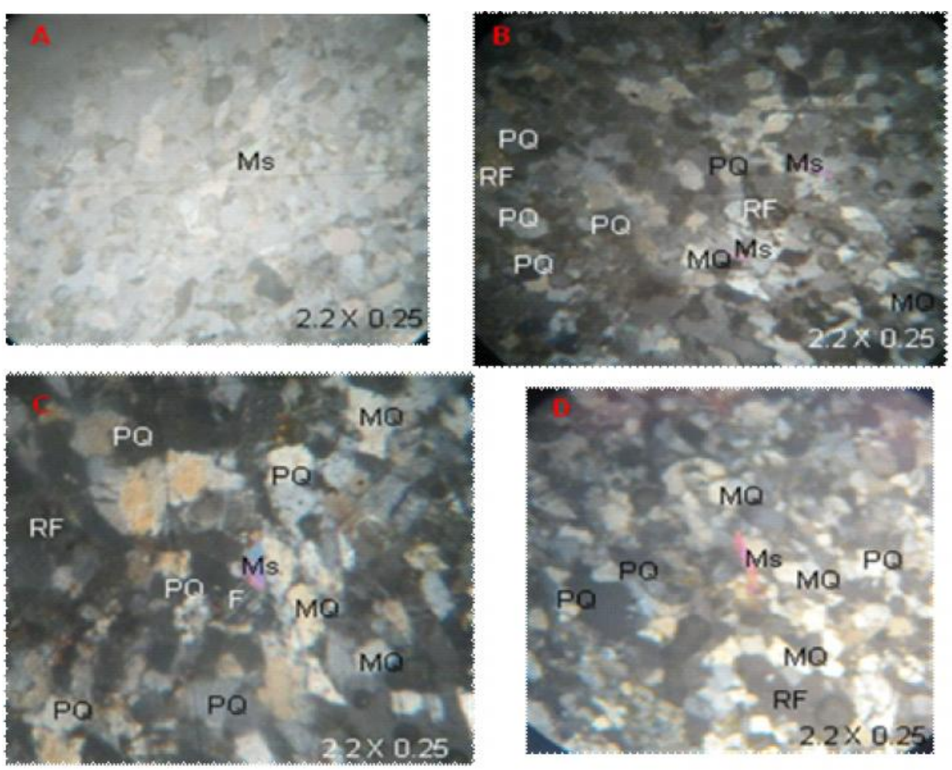

Figure 12: Photomicrographs of samples from L/10; A (Plane polars) and B, C, D (Cross polarized light). (F) feldspar, (Ms) muscovite (MQ) mono crystalline quartz, (PQ) polycrystalline quartz and (RF) rock fragment

4.4 Depositional environment

Several independent analyses have been carried out to enable an integrated reconstruction of the depositional environments within the study area, during the deposition of the Konshisha River Group and Ezeaku Formation. Detailed facies analysis identified the oldest sediments in the study area to be the limestone and grey shale facies. Zaborski (2000) had dated these sediments Early Turonian based on the occurrence of planktonic foraminifers, ammonites and inoceramid bivalves. The encountered limestones (mid- to dark grey, fine grained, fossiliferous wackestones) were deposited in an overall shallow marine ("carbonate ramp-type") setting, within an oxygenated, low-energy, inner ramp/lagoonal environment. This accounts for the fine-grained and fossiliferous nature of the deposits (Burchette and Wright, 1992). The lagoon was unlikely to have been highly restricted, inferred based on the relatively high diversity of fossilized species. Occasional rippled surfaces develop during periodic wave incursion. In some locations, limestones are laminated or interbedded with laminated shales, indicative of low-energy, lagoonal conditions. Petrographic study suggests limestones are dominated by mudstone, wackestone and occasional packestone lithologies, which are typical lagoonal sediments (Burchette, and Wright, 1992). Furthermore, the presence of detrital quartz grains in thin sections may indicate proximity to a paleo-shoreline (Fig. 13). Similar interpretations were made in the study of Cenomanian – Turonian age sediments in the Ashaka area, Northeast Nigeria (Gebhardt, 1997).

Continued marine transgression and increasing water depth led to widespread deposition of grey- to dark grey, fissile-laminated shales (Facies C) across the Benue Trough. Marine transgression was likely the result of eustatic sea-level rise and/or continued rifting (Benkhelil, 1989), accompanied by lower oxygen levels and possibly, reduced salinities (Gebhardt, 1997). The grey-shale facies was deposited in a low energy, relatively low oxygenated conditions, open marine shelf environment, in water-depth probably less than 50 m (e.g. Gebhardt, 1997), and may have signalled the peak of lower Turonian marine transgression in the Benue Trough (Fig. 13).

A short regressive event ensued in the late Turonian times, with the deposition of the micaceous and ripple-laminated sandstone (Facies A). In other parts of the Benue Trough, this sandstone unit developed into what is formally referred to as the Agala (Ogoja/Konshisha) Sandstone and Markurdi Sandstone formations (Nwajide, 1990). The sandstones are creamy to whitish, fine-grained, poorly to moderately sorted sub-litharenites, with sub-angular grains that are both texturally and compositionally sub-mature and possibly derived from a nearby source (or multiple sources). Facies analysis integrated with grain size analysis (bivariate and multivariate plots) suggests that the sandstones were deposited in a fluvially-influenced shallow marine/near shore environment. The poor to moderate sorting and fine grained nature of the deposits may indicate deposition by fluvial processes; possibly the lowermost course of a river. However, the symmetric geometry of ripple bed surfaces, as well as observed shaly inclusions (rip-up clasts) suggests a relatively high energy, wave-influenced shallow marine environment. This "mixed fluvial-shallow marine signal" is typical of deltaic/near-shore deposits. A fluvially-influenced near-shore environment for the deposition of the micaceous sandstones and siltstone is the preferred interpretation in this study (Fig. 13).

Post-depositional Santonian compressional tectonic event, oriented NW-SE, resulted in large scale deformation, uplift and tilting of beds; the imprints of which are observable on the Lower Turonian deposits as steeply dipping, intensely fractured beds, with common calcite or pyrite infilling of fractures; and at the microscopic scale, elongate mineral grains with line grain contacts.

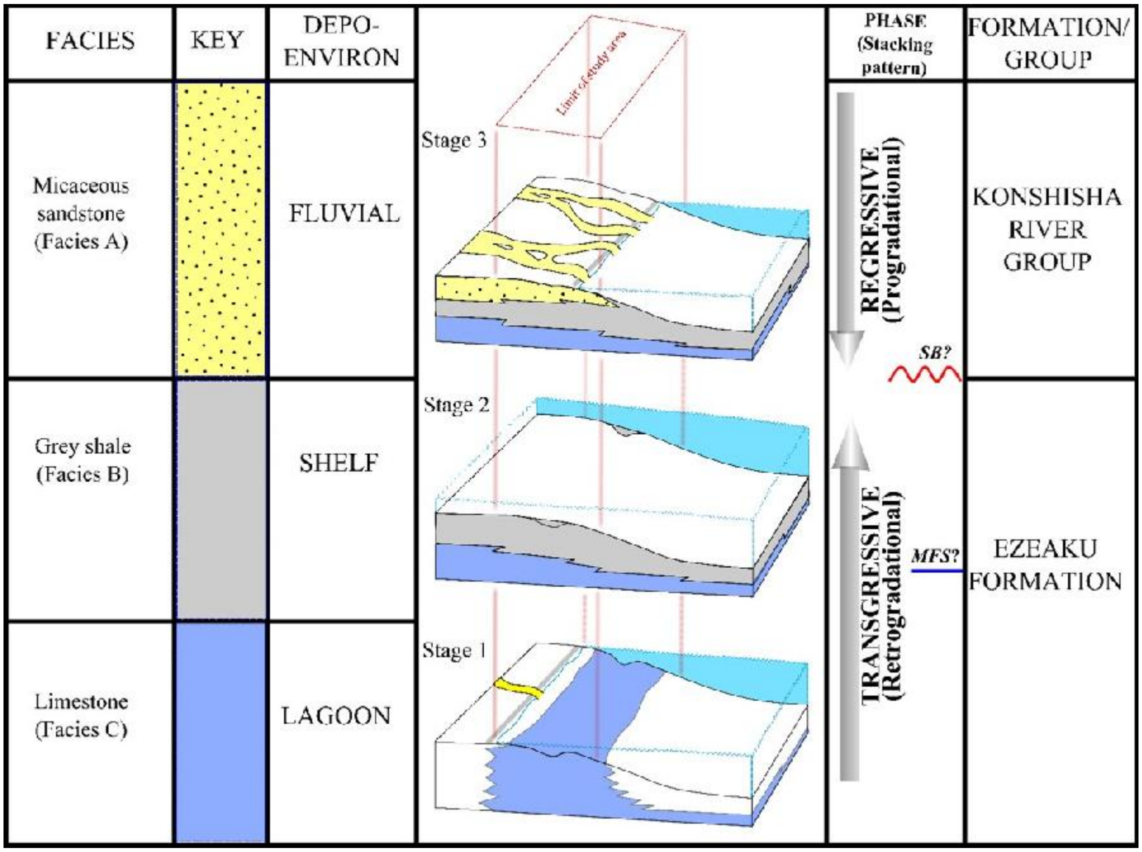

Figure 13: Schematic conceptual models showing the facies units and their depositional environments during the Turonian period. Shazam lines show initial retrogradation (transgression) and little or no clastic sediment input during Stages 1 and 2, and subsequent progradation (regression) during Stage 3

CONCLUSION

In this study, descriptive lithofacies analysis integrated with detailed petrographic and granulometric analysis has enabled reconstruction of the depositional framework of the lithologic successions observed in areas around Konshisha, southern Benue Trough. The dominant lithologies encountered belong to the Lower Turonian Ezeaku Group. About fourteen outcrop locations were studied with emphasis on the textural and mineralogical characteristics of the rocks. Field studies shows that the sediments are mainly limestones towards the southern part of the study area and sandstones/siltstones towards the north. Textural analysis indicates that the sandstones are fine grained; mean grain size range from 2.23 phi (0.21 mm) to 2.77 phi (0.15 mm) (fine sand), sorting ranged from 1.43 phi to 2.02 phi (poorly to very poorly sorted), skewness ranged from -0.32 phi to 0.12 phi (near symmetrically skewed), while kurtosis ranged from 0.97 phi to 1.11 phi (mesokurtic). A maturity index of 4.88 implies that the sandstones are compositionally sub-mature. They are classified as sub-litharenites deposited not far away from the sediment source, hence are texturally sub-mature. The limestones are composed of micrite, skeletal fragments, sparite, calcite recrystallized bivalve shells, pelloids and detrital grains (quartz and muscovite), and are dominated by mudstone, wackestone and occasional packestone lithologies. Based on the integrated analyses, the depositional environment of the sediments in the study area was overall, a shallow marine setting. The mudstones and limestones were deposited in a shelf and inner ramp/lagoonal environment, respectively, while the sandstones were deposited in a fluvially-influenced shallow marine environment.

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