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Diagenetic Impact on Eocene Sands of Upper Ameki Group, Southeastern Nigeria

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Abstract: *The fabric properties of the Eocene sand unit of the Upper Ameki Group evolve with time as minerals tend to attain equilibrium with the environment and show heterogeneities that vary spatially. The unconsolidated sands are composed mainly of quartz, plagioclase, feldspar and kaolinite while the sandstone is composed dominantly of quartz, hematite, and goethite with no significant presence of kaolinite. This study identifies and evaluates in macro- and micro-scale, the various diagenetic imprints on these Eocene litho-units. It, therefore, further enumerates the impact of these post-depositional changes on fabric characteristics, which are dependent on mineral stability, mineral presence and properties of aqueous fluids in pores.*
Keywords: *Compaction, Dehydration, Diagenesis, Dissolution; Fracturing; Weathering; Replacement*

I. Introduction

The post-depositional change in sediments influences presents physical and chemical characteristics. These changes are products of physical compaction, chemical compaction, precipitation, relatively unstable mineral dissolution and replacement. Each of these processes results in the formation or replacement of a mineral. Authigenic minerals are products of diagenesis and they influence fabric characteristics. The source of silica or quartz cementation [1], quartz and feldspars replacement by calcite [2] and mineral transformation especially clays [3] have well documented diagenetic effect in sands.

The higher the quartz content the greater the mechanical stability of sands, whereas low quartz content implies low chemical stability due to cementation and dissolution [4]. Sands with abundant lithic, feldspar or chert have less occlusion of porosity. Diagenetic processes are active as environment tends to balance temperature, pressure and chemistry during deposition, burial and tectonic changes within basins. These diagenetic processes evolve with time and this study evaluates the impact of diagenesis on the mineralogy of Eocene sands in the Upper Ameki Group.

II. Study Area and Geologic Setting

The study area (Fig. 1) is in Anambra State in southeastern Nigeria, and it belongs to the outcropping sediments of the Niger Delta [5]. The study cuts across Nsugbe, Awkuzu, Umunya and Onitsha prisons area.

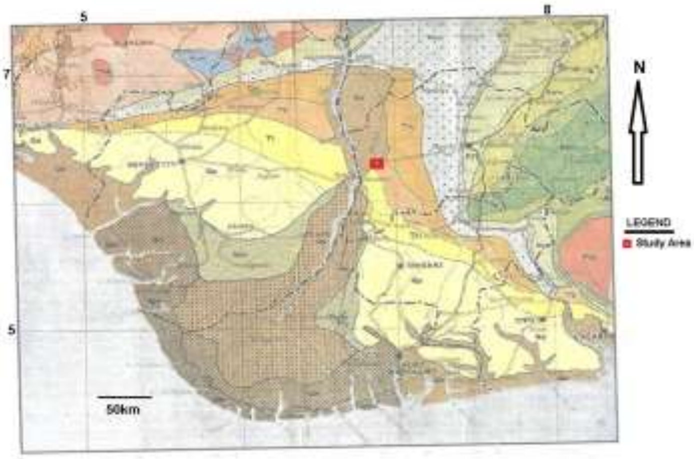


Figure 1: Map showing study area.

The road network is relatively good and comprises of tarred roads like the Enugu-Onitsha expressway and Nkisi road as major roads while there are track roads and footpaths for improved accessibility of outcrops within the study area.

The landform shows a highland and lowland region which generally, is undulating. The study area is drained dendritically towards the south. This is a typical case where geologic boundaries differ from geographic boundaries. These Eocene sands are lithologic units of the Ameki Group [6].

Table 1: Outcropping Units of the Cenozoic Niger Delta [5].

AGE	LITHOSTRATIGRAPHY UNITS	
Oligocene-Present	Benin Formation	
Oligocene-Miocene	Ogwashi to Asaba Formation	
Eocene-Early Oligocene	Ameki Group	Nsugbe Formation
		Nanka Formation Ameki Formation
Paleocene-Early Eocene	Imo Formation	

III. Methodology

Outcrop studies were conducted and samples collected for grain size analysis, thin section petrographic studies and XRD to identify authigenic to detrital minerals present. The polarizing microscope and panalytical X'Pert Pro diffractometer utilized were accurately calibrated before used.

IV. Result And Discussion

The post-depositional changes in the Eocene sands are physical, chemical and biological and these changes may have occurred during sediment to water interfaces and after burial. The unconsolidated sands at Awkuzu-Umunya and Nneyi Umuleri show the presence of pebbles with well-preferred orientations. These sands show the presence of burrows with complex network structures that belong to *Scolithos Ichnofacies* like *Scolithus* and *Ophiomorpha*.

The sands have a varying thickness within the range of few meters and at Awkuzu and they are interbedded with ferruginized sandstone of average thickness that is less than five centimeters (<5cm). The sands are well stacked and grain to grain or grain to fluid interaction results in grain rearrangement, fracturing, cracking of pebbles and pore collapse. Grain size rearrangement and fracturing are a major influence of compaction [7]. These sediments are rich in quartz and are dominantly fining upward. They are fine to very coarse loose sands. The sands show the presence of burrows belonging to *Scolithos Ichnofacies* (Fig. 2). The sediments are texturally more mature towards south and they are classified as quartzarenite.

(a) (b)

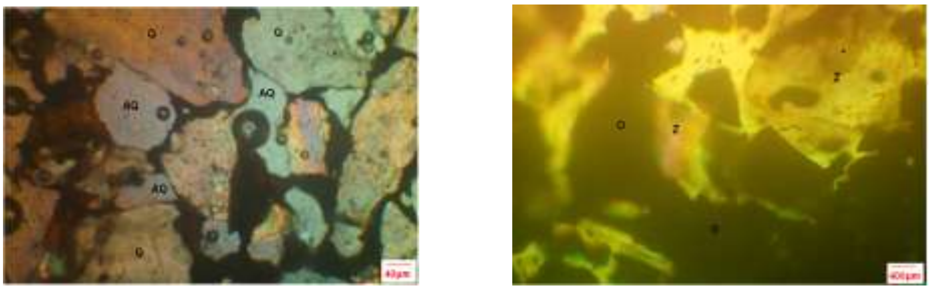
Figure 2: (a) Convolute laminations and plastic deformational structures. (b) Burrows.

At Nsugbe and Onitsha prisons area, the sands are well indurated and with increasing impact of weathering and high imprint of marine influences. These indurated sands based on outcrop facies relations are probably a product of diagenesis due to interaction with the environment. On a macro-scale, they show the presence of convolute laminations which are probably products of plastic sediment deformation by dewatering due to mechanical differential compaction (Fig. 2). They are classified as sublithicarenite and lithicarenite.

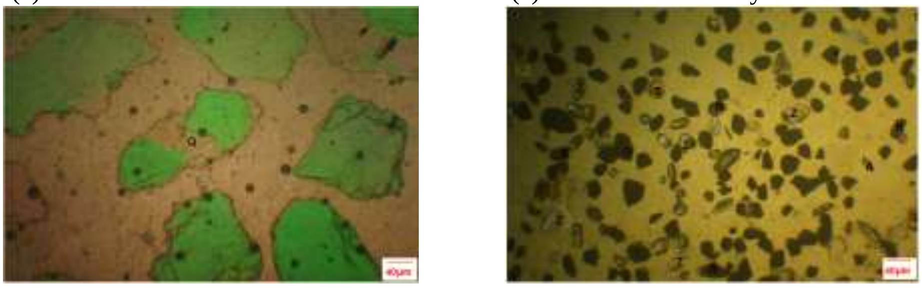
Sand pockets within sandstones exist as discrete nodules and they originate from differential loading of waterlogged sands on unconsolidated clays [8]. Characteristics of surface morphologies such as indentation marks, interpenetrating grains, and sutured grains are evidence of porosity reduction by pressure solution. On a micro scale, they are evidence of micro-fracturing, mechanical compaction, chemical compaction, mineral dissolution, replacement, cementation, and weathering. Generally, the grains are dominantly angular to subangular, subrounded poorly to moderately sorted, coarse sands on microscopic scales. The micro-intergranular porosities for the unconsolidated sands are good to excellent using visual approximation.

The sands are dominantly composed of quartz, plagioclase, K-feldspar and kaolinite as revealed by XRD results while the sandstones in the study area are rich mainly in quartz, goethite, and hematite, with no kaolinite presence. Quartz is most abundant and ranges in composition from 65% to 95% in these Eocene lithostratigraphic units.

The grains show the presence of opaque minerals which are probably iron oxides and oxyhydroxides coating edges and filling fracture zone. Authigenic Quartz (AQ) overgrowths are optically continuous with substrate minerals forming a syntaxial fabric (Fig. 3).



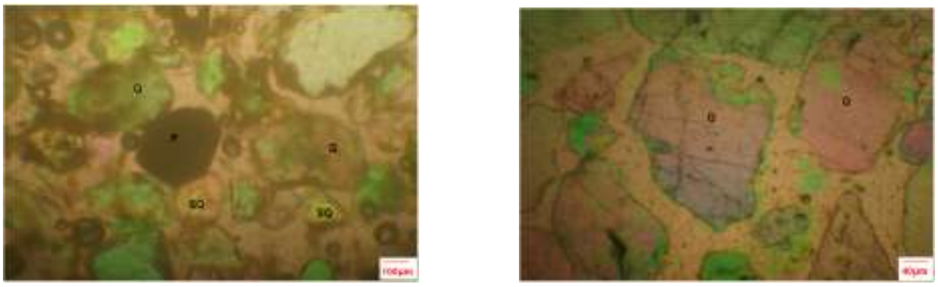
(a) Sandstones – Normal slide (c) Sandstones – Heavy mineral slide



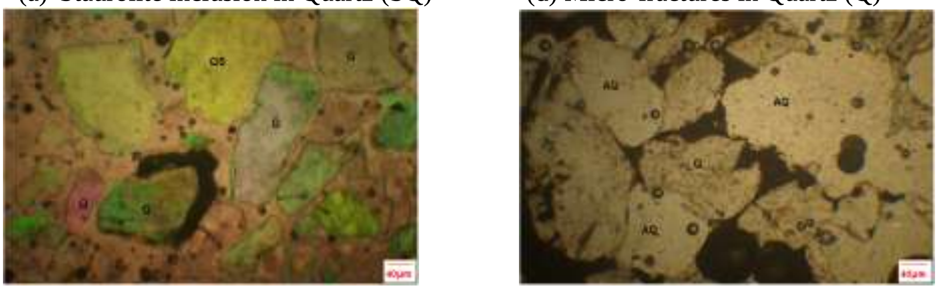
(b) Sands – Normal slide (d) Sands – Heavy mineral slide

Figure 3: Photomicrograph of Eocene sands of Ameki Group. Note: Authigenic Quartz (AQ), Quartz (Q), Zircon (Z), Rutile (R), Tourmaline (T) and Opaque (O).

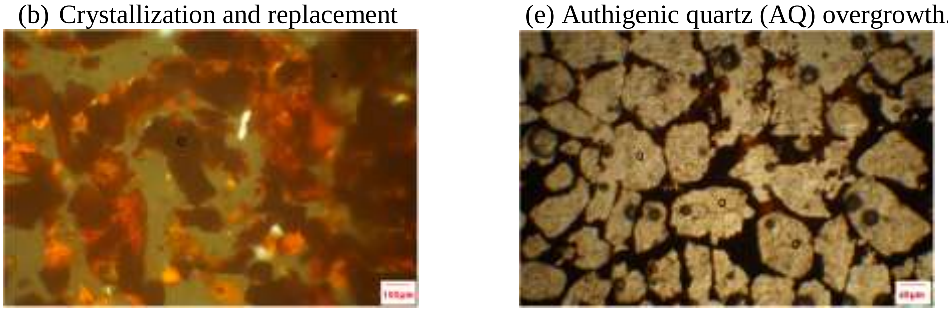
The quartz grains (Fig. 4) show fractures that are both isolated and complex. The complex fractures are composed of numerous Intragranular fractures. Isolated fractures are present as single fracture traces which commonly emanate from grain boundaries.



(a) Staurolite inclusion in Quartz (SQ) (d) Micro-fractures in Quartz (Q)



(b) Crystallization and replacement (e) Authigenic quartz (AQ) overgrowth.



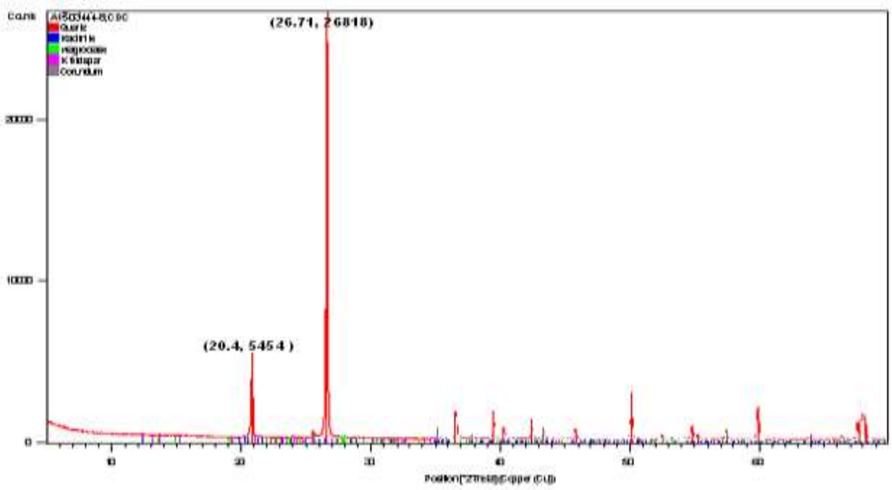
(c) HM replacement by iron minerals (f) break down of mineral structure by weathering

Figure 4: Photomicrograph showing the typical diagenetic process in Eocene sands of Upper Ameki Group. (HM=Heavy minerals)

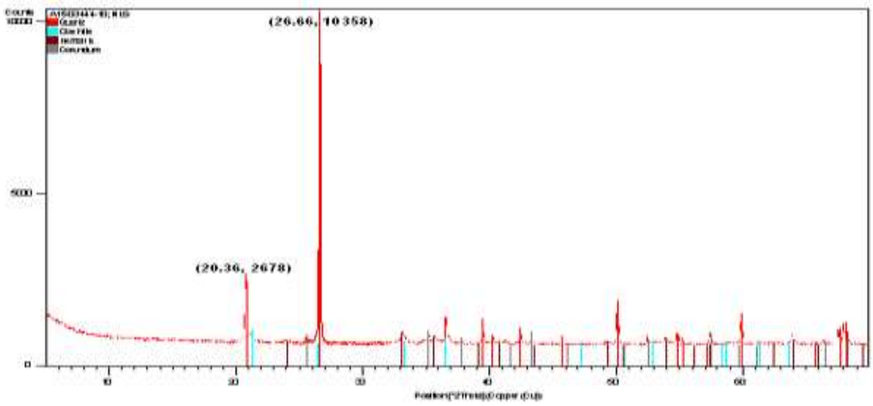
Micro-fractures tend to increase intragranular porosity within grains. The intensity of fracturing and extent of fragmentation reflects the degree of deformation by compaction. Relatively, sands are not easily compacted like mud and clay due to support by grain to grain contact. Compaction with a high content of ductile lithic fragments probably resulted in the induration of sediments and with the precipitation of cementing materials, the degree of induration in sediments increases.

The common cement materials in Eocene sands of the Upper Ameki Group are authigenic quartz (AQ), iron minerals (hematite and goethite) and clays (kaolinite) as identified by XRD mineral results (Fig. 5). Cement precipitated in pores, coating grains and increasing grain to grain contact which decreases intergranular pore spaces (porosity). Cementation depends on the chemistry and amount of pore fluids.

The driving mechanisms for the diagenetic reaction are changes in one or more ambient pore-fluid chemistry, temperature, and pressure. It is the presence of unstable minerals (like feldspars) or metastable components which are bathed in aqueous pore water charged with dissolved species that define the diagenetic system. These diagenetic processes evolve with time.



(a) Unconsolidated sands



(b) Sandstones

Figure 5: Typical minerals identified using XRD pattern for Eocene sands of Upper Ameki Group.

Hematite (Fe_2O_3) cement forms in an oxidizing environment. Fe^{2+} dissolves from ferromagnesian minerals during diagenesis and gets oxidized further into Fe^{3+} which precipitates as hematite cement. Kaolinite requires low pH, low ionic strength waters and are typical of early diagenesis in this fluvio-tidal sediments. They are known to form "book-like" that occupy and locally fill pores. The sandstones at Nsugbe and Onitsha Prisons area are highly affected by weathering. This area is bordered westward by the Anambra River and is drained dendritically by surface water bodies named Oyi, Nkisi and Obele Nmiri. The extent of flushing of this water may have influenced the rate of weathering of sandstones.

Paragenetic Sequence

The results obtained are used to infer the order in which diagenetic processes occurred in the Eocene sand of Upper Ameki Group (Fig. 6). As deposition increases the weight of the overburden pressure and re-settlement of sediments begins the process of physical compaction. Physical or mechanical compaction is intense in the first few meters of burial and continuous until the closest grain aggregate packing arrangement is reached within Eocene sands.

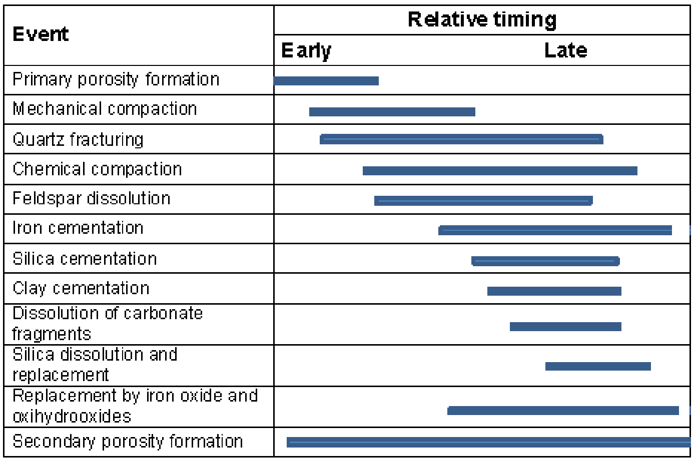


Figure 6: Paragenetic sequence of Eocene sands.

Mechanical compaction is followed by chemical compaction and both have an influence on the porosities. Chemical compaction involves chemically induced grain dissolution at intergranular contact and re-precipitation of dissolved material on grain surfaces facing open pores. Though, the present porosity of these fluvio-tidal Eocene sands is a function of depositional porosity, burial depth, compaction and mineral cement growth in pore network. The solubility of silicate minerals increases with increasing pressure and temperature which are associated with increasing burial depth. Feldspars due to their unstable nature easily undergo dissolution.

Compaction, dissolution, mineral alteration and replacement result in the formation of secondary porosity [9]. The iron minerals which are probably iron oxides and oxyhydroxides gradually alter and replace other minerals, filling the intergranular pore spaces. Eventually, these increase the degree of induration as observed in ferruginized sandstone at Awkuzu and are described as potential seals that compartmentalized Nanka sands, forming good trapping mechanism [10].

V. Conclusion

Generally, compaction, cementation and mineral replacement especially by iron minerals that are probably iron oxides and/or oxyhydroxides, have a dominant impact on fabric characteristics. To attain a relatively stable balance with spatially heterogeneous environmental conditions, Eocene sands responds to grain rearrangement, plastic deformation of the ductile component, fracturing, mineral dissolution, recrystallization, and replacement. The post-depositional changes undergone by the fluvio-tidal Eocene sands of Upper Ameki Group defines its present fabric characteristics and this study successfully evaluates and enumerates these diagenetic processes, to reduce the knowledge gaps and consolidates the understanding of Eocene sands history.

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