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Preliminary data from outcrop studies and petrographic analysis of relict pre-Santonian gravels near Auchi, Edo State, Nigeria

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ABSTRACT

The western fringe of the Anambra Basin has traditionally been regarded as a stable platform during the pre-Santonian period. This study presents preliminary data on recently discovered pre-Santonian rocks, depicting a more complex paleodepositional history than previously postulated. The pre-Santonian rocks occur as poorly sorted, lithified, clast-supported gravels with angular to subrounded clasts, outcropping as boulders distributed along a gently sloping elliptical ridge. Sedimentary structures, including graded bedding and crossbedding with centimetre- to decimetre-scale foresets, observed within the succession, together with the textural characteristics, depict a braided river palaeoenvironment. Furthermore, petrographic analysis reveals monocrystalline quartz as the dominant framework mineral, with minor feldspar, rock fragments, and zircon. The abundance of angular to subangular grains, together with the poor sorting, indicates immature to submature textural maturity consistent with first-cycle sediments. Similarly, the framework composition reflects immature to submature compositional maturity, derived from felsic provenance, hypothesized as the Precambrian Igarra Schist Belt.

1. Introduction

Sedimentary rocks are archives of physical, chemical, and biological processes that prevailed at particular times in the Earth's history. The paleo-physical processes can be deduced from the depositional sedimentary structures, strata thicknesses, together with the sizes, shapes, degrees of roundness, and sorting of sedimentary particles. Chemical paleo processes can be deduced from colour, fossils (body and trace), mineralogy, and geochemistry of the sediments, etc., while biological processes can be inferred primarily from the fossil content.

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The foregoing characteristics have been used in unravelling Cretaceous to Recent paleo-sedimentary processes across the sedimentary basins in Nigeria (1-7).

Pre-Santonian rocks have been reported in the Benue Trough, Chad Basin, Dahomey Basin, and Sokoto Basin by several authors (1,3,8,9,10,11,12,13). Detailed sedimentological investigations on pre-Santonian sandstones using petrographic, granulometric, and heavy mineral techniques revealed that the pre-Santonian siliciclastic sequences are indurated, cross-bedded, texturally immature to submature, subarkosic, and sublitharenites from a continental block provenance (3,8-14). Additionally, the sandstones possess claystone and conglomeratic facies (3,10,12), interpreted under a fluvial and fluviomarine paleoenvironment.

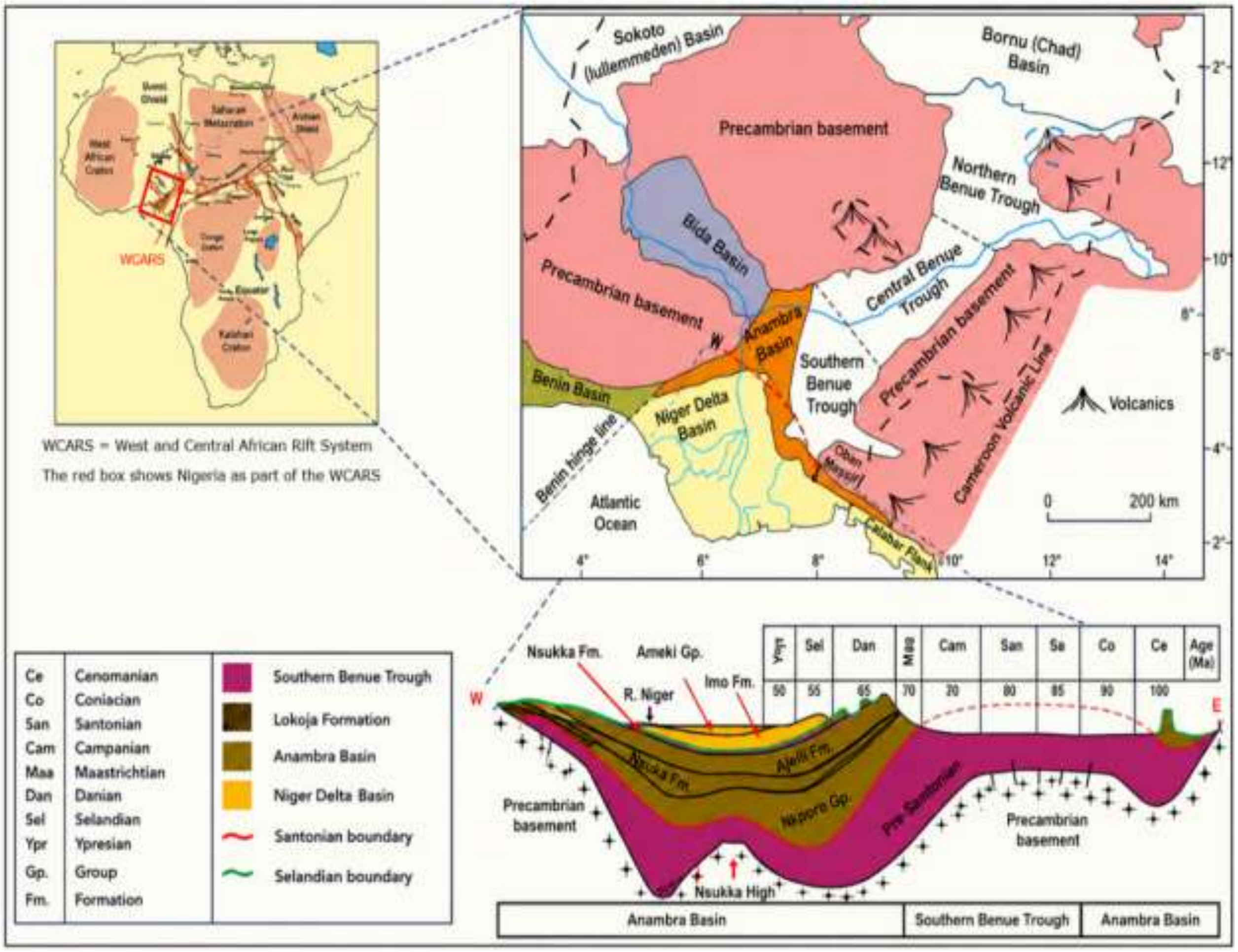

Figure 1: Map showing areas underlain by sedimentary basins versus areas underlain by Precambrian rocks in Nigeria. Notice the W-E cross-section revealing pre-Santonian to Ypresian stratigraphy (Adapted from 15,16).

The western fringe of the Anambra Basin (Fig. 1), which was part of the southern Benue Trough, Nigeria, has been thought to be a platform during the pre-Santonian, which presupposes that it could not have been a repository for sediments (17-19). However, field mapping over the last seven years has revealed an outlier of pre-Santonian rocks, which are hypothesized to be coeval with pre-Santonian strata within the Benue Trough (6). This discovery suggests that the paleodepositional history of the region is considerably older and more complex than previously recognized. Against this backdrop, field investigations were undertaken at Ago-Isame, near Auchi, Nigeria (Fig. 2), to generate preliminary sedimentological data on these strata.

This study presents detailed field descriptions of the rocks and evaluates their depositional characteristics to reconstruct the prevailing paleodepositional environment.

2.0. Geologic Setting

Geodynamically, the Benue Trough forms part of the larger West and Central African Rift System (WCARS) (Fig. 2), which developed in response to stresses associated with the opening of the South Atlantic Ocean during the Barremian (20,21). Its pre-Santonian tectonostratigraphy comprises a syn- to post- transtension cycle, which was truncated by transpression during the Upper Cretaceous (Santonian – Maastrichtian) (6,21).

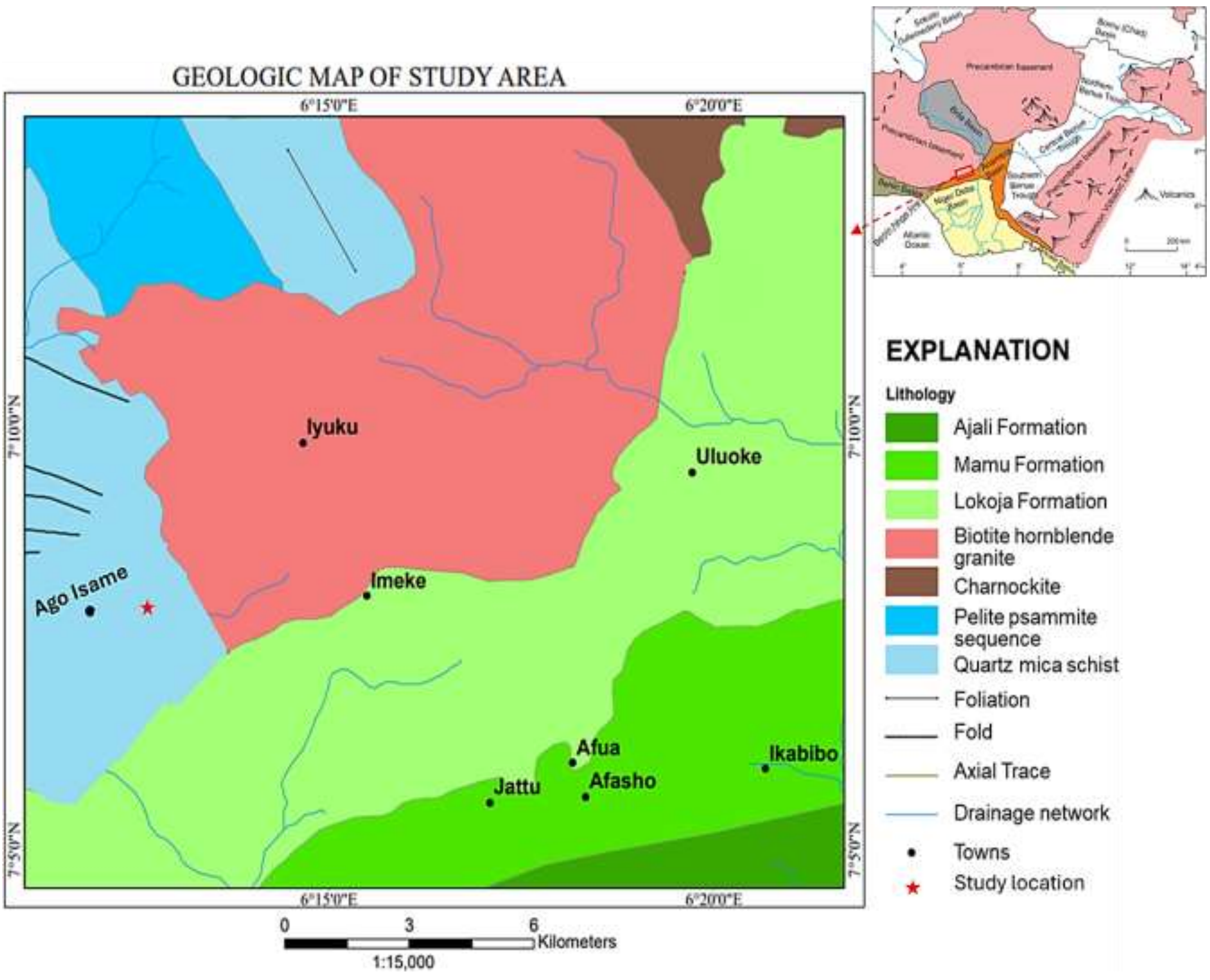

Fig. 2: Geologic map of Ago – Isame and environs

The progressive opening of the South Atlantic Ocean and the final separation of the African and South American plates during the Albian (22) facilitated a major marine transgression into the Southern Benue Trough. This transgressive event led to the deposition of the Asu River Group over the older feldspathic to lithic sandstones, which overlie the Precambrian rocks (Fig. 3). Continued global sea-level rise intensified the marine incursion, which persisted through to the Turonian, reaching highstand around the Cenomanian–Turonian boundary (19,23).

During this period, marine waters from the Equatorial Atlantic became connected with those of the Tethys Ocean, establishing the Trans-Saharan Seaway through the Benue Trough (6,23). This extensive seaway provided the conditions for the deposition of the Eze-Aku and Awgu groups (24,25).

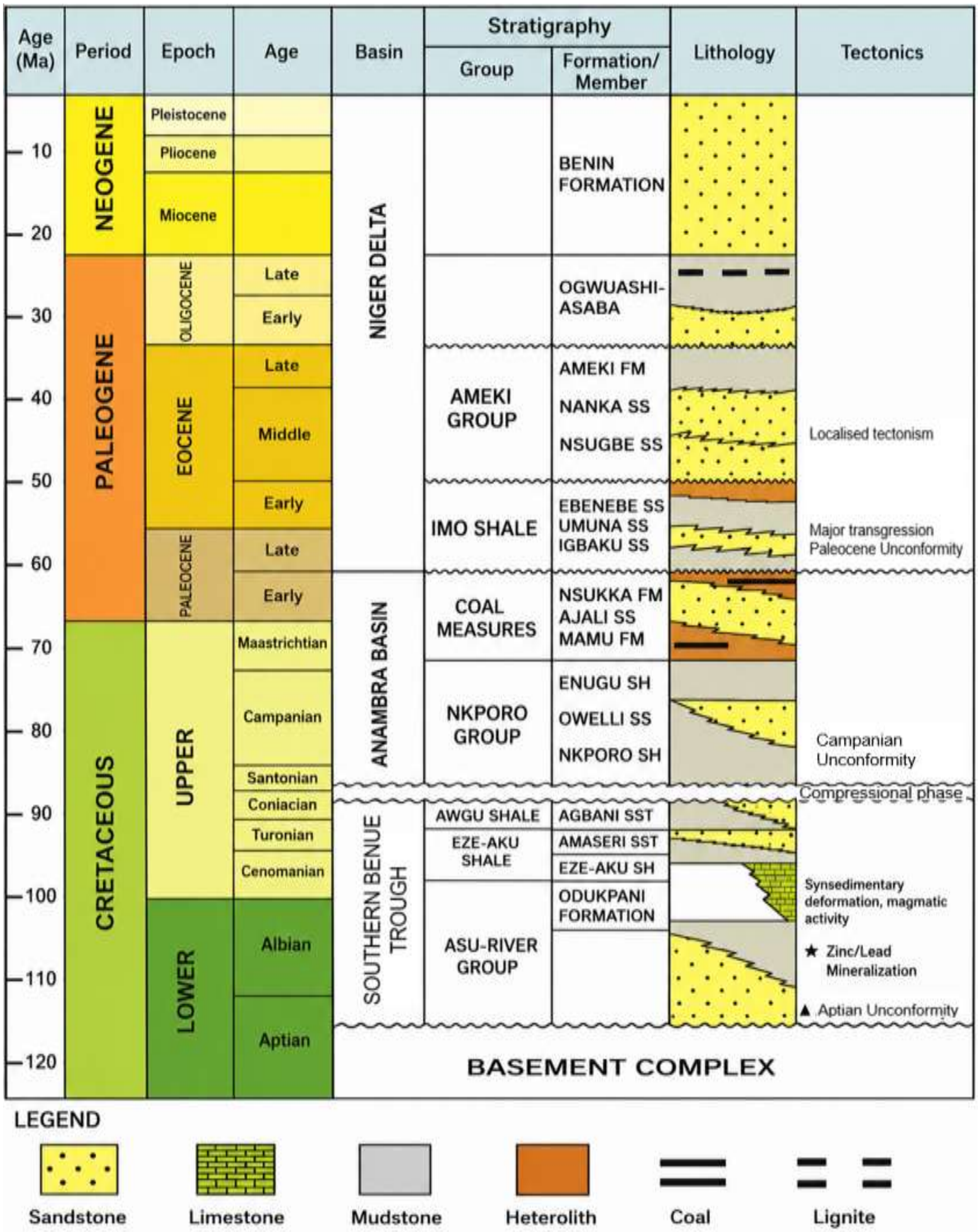

Fig. 3: Tectonostratigraphy of the Southern Benue Trough showing the Anambra and Niger Delta depositional phases (Adapted from 4).

In the Southern Benue Trough, the Cenomanian to Coniacian is represented by the Eze-Aku and Awgu groups (Fig. 3). The Eze - Aku Group is composed predominantly of highly fossiliferous calcareous mudstones interbedded with sandstone and limestone units. These sediments accumulated across a broad spectrum of depositional settings, ranging from shallow-marine environments to deeper marine conditions (26,27). The Awgu Group conformably overlies the Eze-Aku Group and is composed mainly of alternating beds of mudstone, limestone, and marl, with minor sandstone intercalations (25). Coal seams persist near the top of the succession, showing periods of increased terrestrial influence and organic matter accumulation. The sedimentological and paleontological characteristics of the Awgu Group suggest deposition under environments ranging from delta plain settings to shallow marine conditions (14,24,26).

3.0 Methodology

The methodology involved field descriptions, including mode of occurrence, textural analysis, and particle-size estimation using a standard grain-size comparator chart (28), followed by petrographic thin-section analysis. The observations from the field studies and thin-section analysis were thereafter integrated and used to infer maturity and depositional environment.

4.0 Results and Discussion

4.1 General field observations

The pre-Santonian strata occur as an outlier within metasediments of the Igarra Schist belt, close to the fault-bound interface between the Basement Complex and the Anambra Basin. The rocks outcrop as large boulders in the study area, covering circa 100 m^2 (Fig. 4). On the topographic map, the outcrop is on a NW – SE trending gently sloping ridge (600 m) with an elliptical outline (Fig. 4a). Unweathered samples were observed to be highly lithified and off-white in colour (Fig. 4b). The sedimentary particles are polymodal, with grain sizes ranging from approximately 1 mm to more than 1 cm, although grains larger than 2 mm are dominant (Fig. 5). Additionally, the particles are poorly sorted and exhibit angular to subrounded shapes (Fig. 5). Sedimentary structures observed in the boulders include normal grading and crossbedding, characterized by centimetre- to decimetre-scale foresets that progressively decrease in thickness (Figs. 5c, 6a). Petrographic analysis shows quartz as the dominant framework mineral, with feldspar, zircon, and lithic fragments occurring in accessory amounts (Figs. 6b -d), which is consistent with observations in the eastern flank of the Southern Benue Trough (3,8,9) and in the Northern Benue Trough (29). Additionally, the grains show concavo-convex contact, as well as silica cement, evidenced by quartz overgrowth (Figs. 6b -d).

4.2 Inferences on paleodepositional environment

The difficulty in differentiating lithofacies within the study area due to the mode of occurrence of the rocks (see 4.1) makes facies analysis untenable. However, we rely on field observations. The dominance of particles > 2mm implies that the deposit is a gravel deposit (Figs. 5b – c). Additionally, the angular to subrounded degree of roundness, poor sorting, graded bedding, cross bedding, and dominance of gravel-sized particles are typical of particles transported over short transport distances and deposited by migrating dunes in a high-energy aqueous medium (Figs. 5b – c, 6a). The foregoing inferences, as well as the elliptical outline, are consistent with descriptions of a braided river clast-supported polymodal gravel (longitudinal ?) bar deposit within a middle-outer alluvial fan paleoenvironment (Fig. 7a) (30,31,32). This deduction agrees with the findings of previous works on pre-Santonian gravels in the Benue Trough (12,13,33).

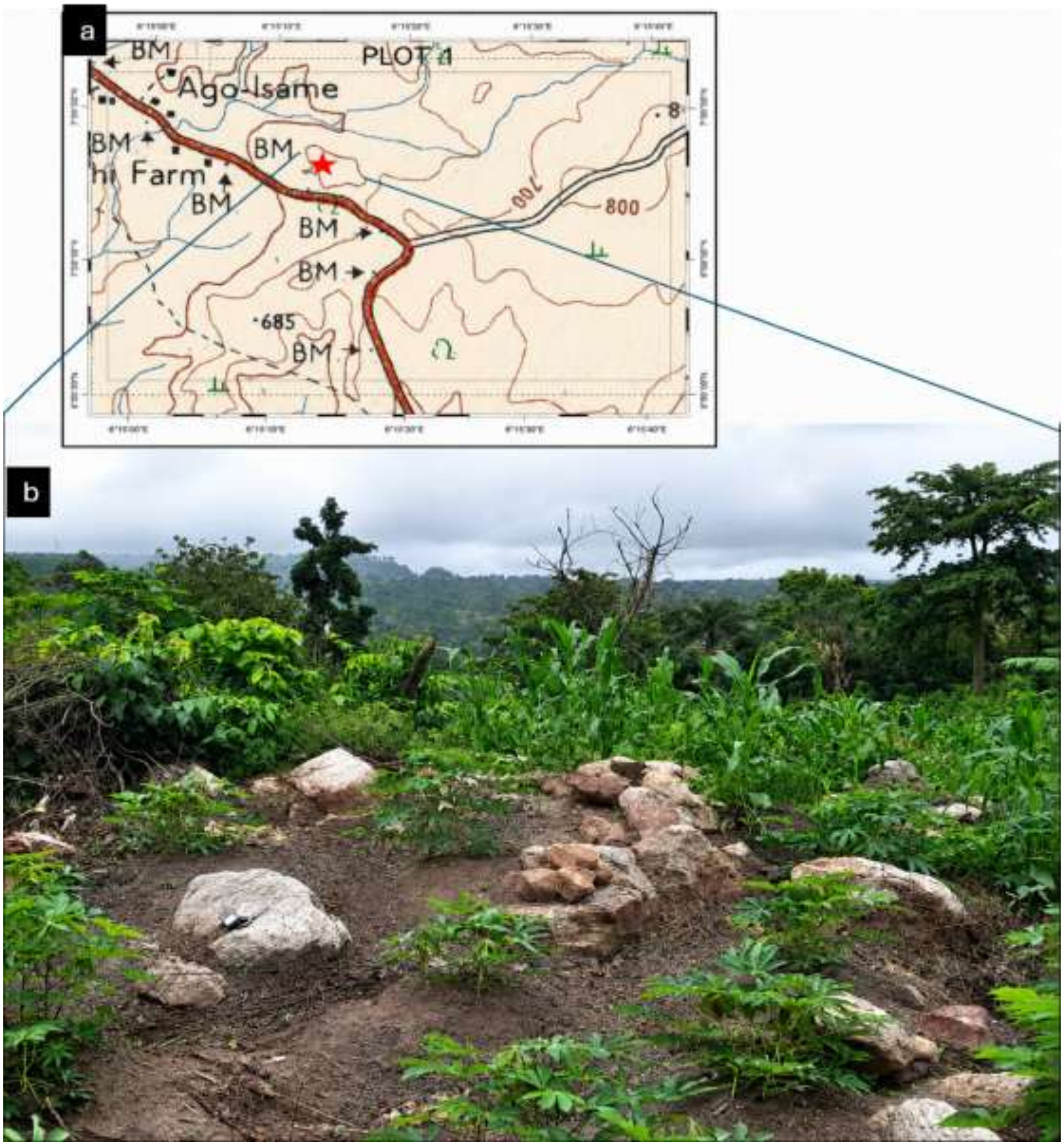

Fig. 4: a, topographic map of the study area showing the NW -SE trending elliptical ridge wherein the pre-Santonian rocks outcrop. b, panoramic view of pre-Santonian rocks in the study area.

4.3 Inferences on textural and mineralogical maturity

Inferences on textural maturity are constrained by the extents of sorting, roundness, and the amount of clay matrix present (31). The poor sorting and angular to subrounded particles (Figs. 5a - c) point to immature to submature textural maturity (31) (Fig 7b). Similarly, the presence of quartz, feldspar, and rock fragments indicates that the gravels are polymictic, clast-supported (31). This implies that the gravels possess low compositional maturity and are first-cycle deposits (31).

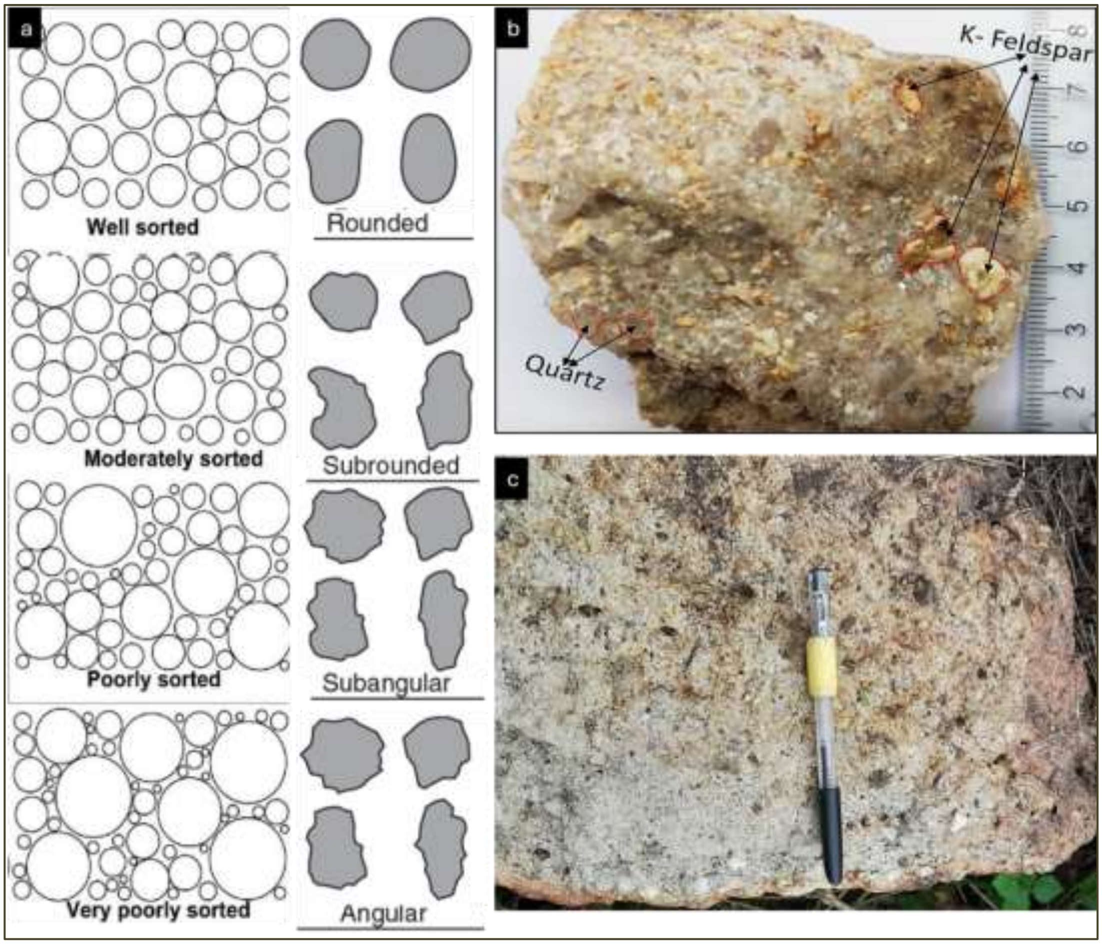

Fig. 5: a, degree of sorting and roundness comparators (modified from 28). b, hand sample with ruler showing mineralogy and size of framework. c, normal grading observed in the rocks

The mineralogy of the framework illustrates a provenance with quartzo-feldspathic mineralogy, which is congruent with the general mineralogy of the rocks in the Igarra Schist Belt (34,35). The foregoing inference is strengthened by the monocrystalline nature of the quartz framework, dominance of potassic feldspar over plagioclase, and zircon crystals, which points to a plutonic granitoidal provenance (36,37,38). This provenance postulation is in concert with reports on pre-Santonian gravels in the Benue Trough (3,38).

4.4 Degree of diagenesis and implications for petrophysical characteristics

The lithified nature of the rocks suggests that the strata have undergone diagenetic changes. Imprints of compaction are represented by fractures within grains, concavo-convex grain contact, and silica cement (Figs. 5b - c, 6a - d), which is promoted by pressure solution and dissolution during mesogenesis (39,40). Stress release due to the Santonian uplift and exhumation of the overlying strata (6,21), as well as telogenetic effects, cannot be excluded, as the rocks that were once buried are now on the surface. As evidenced by the concavo-convex grain contact and formation of silica cement, it is postulated that compaction and lithification of the rocks have led to a reduction in primary porosity and permeability (41,42,43)

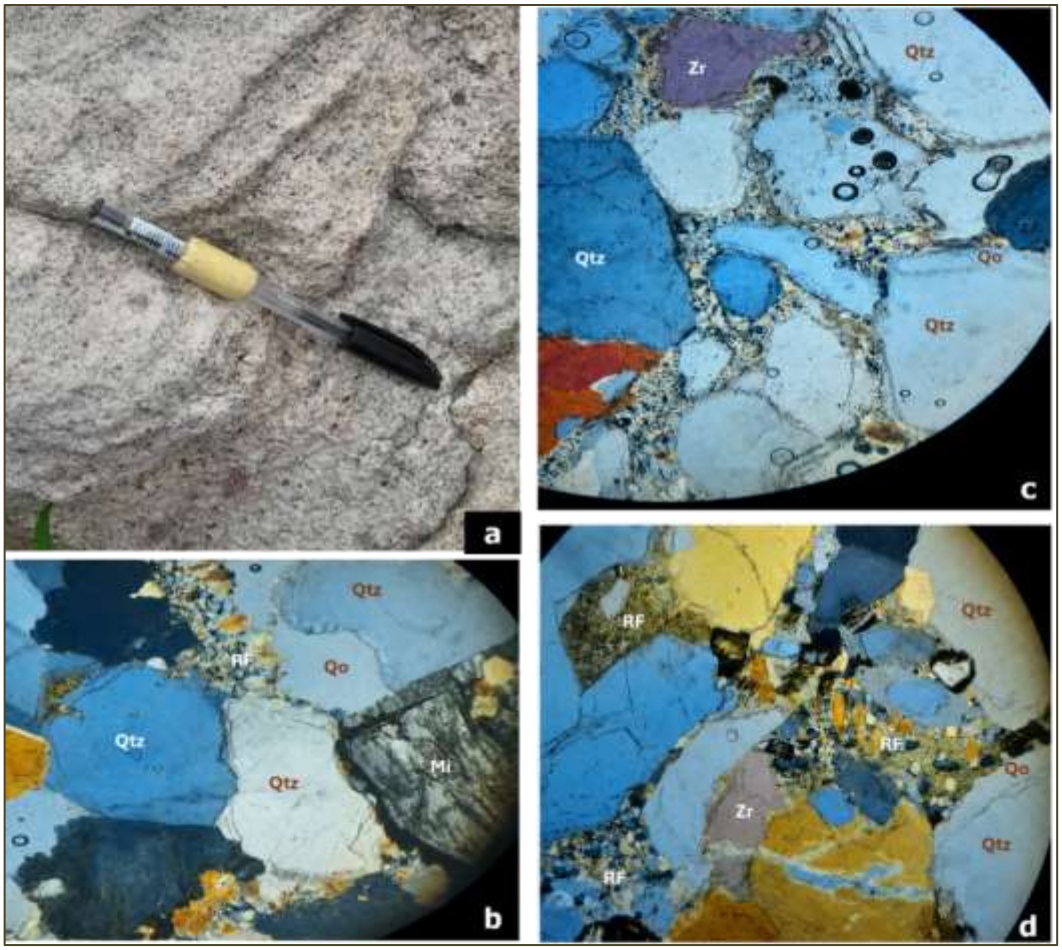

Fig. 6: a, crossbedding with centimeter to decimeter scale foresets. b-d, photomicrographs from petrographic analysis showing mineralogy of framework, concavo-convex contact, grain fracture, and quartz cement. Qtz = monocrystalline quartz, Qo = quartz overgrowth, Mi = microcline, RF = rock fragment, Zr = zircon.

4.5 Implications for basin evolution, groundwater and hydrocarbon exploration

The occurrence of these strata suggests that contrary to previous interpretations (17-19), the western flank of the Benue Trough functioned as an active depocentre during the Lower to Middle Cretaceous (pre-Santonian). Furthermore, provenance studies of the post-Santonian strata in the Anambra Basin indicate significant sediment contributions from both the Precambrian basement complex and the pre-Santonian successions (6). This evidence implies that the preserved remnants of the pre-Santonian strata represent only relics of a once more extensive sedimentary succession, much of which was eroded and subsequently reworked into the Anambra Basin during the Upper Cretaceous (post-Santonian). Their present mode of occurrence (Section 4.1) indicates that these pre-Santonian deposits have a limited spatial extent, thereby precluding them from serving as regionally significant groundwater aquifers or hydrocarbon reservoirs. In addition, extensive diagenetic modification, including the destruction of primary porosity and permeability (Section 4.4), has further reduced their capacity to store and transmit fluids. Nevertheless, the development of secondary porosity and permeability through fracturing may locally enhance their reservoir quality, creating limited zones with improved groundwater or hydrocarbon storage potential.

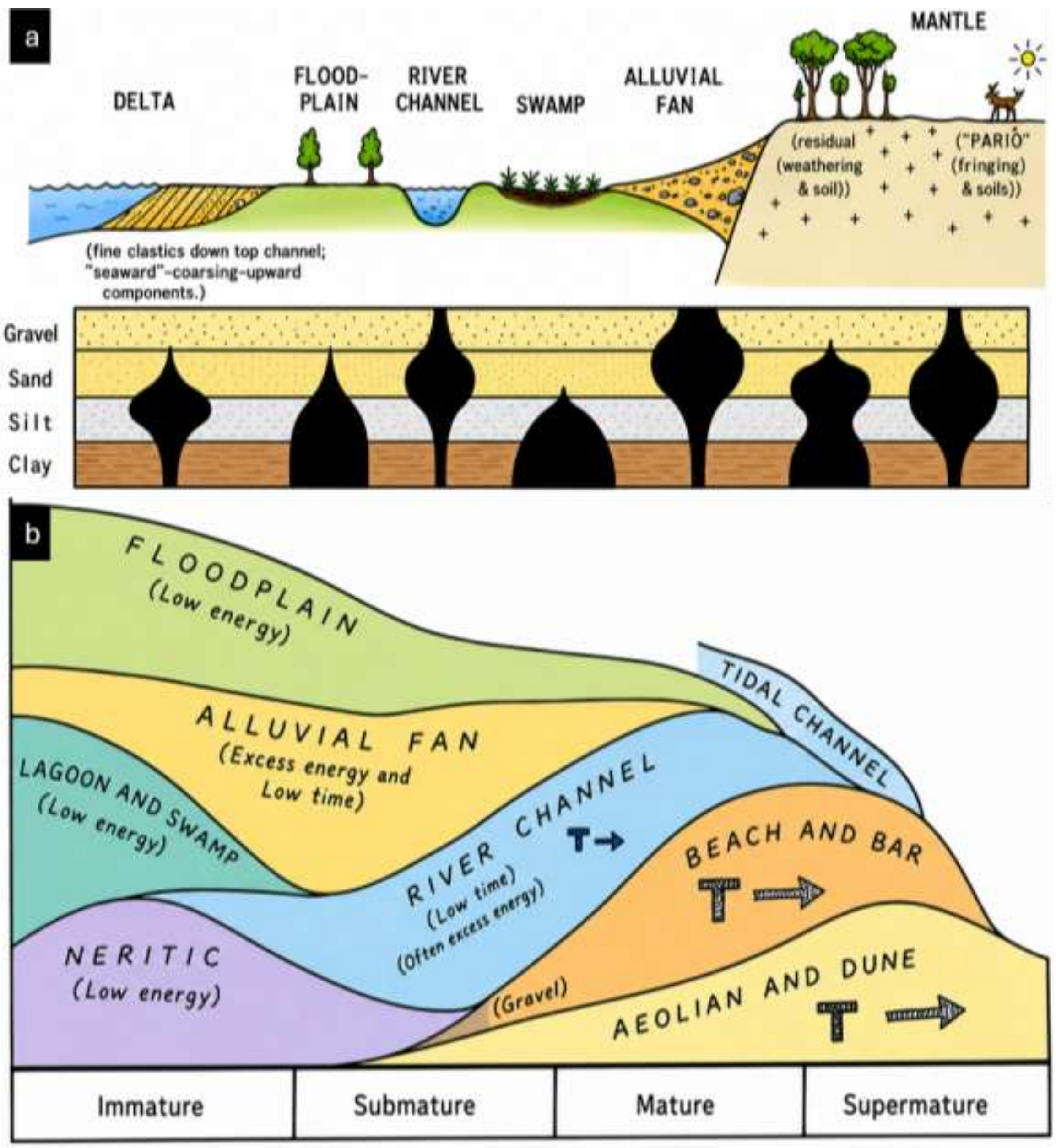

Fig. 7: a, model showing ratio of particle size abundance and depositional environment (adapted from 31). b, model relating textural maturity and depositional environment (adapted from 31).

5.0 Conclusion

The study found that pre-Santonian rocks occur as boulders on a gently sloping elliptical ridge. Field observations and petrographic analysis reveal that these rocks are poorly sorted, lithified, clast-supported gravels with angular to subrounded clasts. Sedimentary structures such as graded bedding and crossbedding with centimeter- to decimeter-scale foresets indicate deposition in a braided river environment. The sediments are composed mainly of monocrystalline quartz, with minor amounts of rock fragments, zircon, and feldspar. Both the textural and compositional characteristics suggest immature to submature sediments derived from a felsic source rock. The likely provenance of these first-cycle sediments is the Igarra Schist Belt located north of the study area.

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