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Mineralogy and Geochemistry of Quaternary Clays in Umukwata, Niger Delta Basin: Depositional Environment, Provenance, and Paleoclimate

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Abstract: *This study involves an exploratory series of sedimentary clay deposits specifically selected to examine sedimentological characteristics using field studies, mineralogical composition, X-ray diffraction (XRD) and major oxides and traces using inductively coupled plasma-mass spectrometry (ICP-MS). This study aims to determine the influence of the mineralogical composition, major oxides and trace elements of clay minerals on the provenance, depositional environment and paleoclimate of Quaternary sedimentary clay deposits in the Niger Delta Basin, Nigeria. The average compositions of nonclay silicate minerals in the study area are quartz 55.0%, orthoclase 17.0%, albite 21.0% and muscovite 7.0%. The major oxides >1 recorded in the study area are SiO_2 = 79.340%, Fe_2O_3 = 2.555%, MgO = 3.010%, CaO = 1.617%, Al_2O_3 = 10.259% and TiO_2 = 1.051%. The trace elements >1 recorded are O 50.370%, Mg 1.815%, Al 5.430%, Si 37.087%, Ca 1.155%, and Fe 1.578%. Ba/Co 5.00, Ni/Co 0.20, Ti/Zr 7.41, Mg/Ca 1.57 and Si/Al 6.83. Field studies revealed that the clay formation in the study area comprises laminated, burrow clay facies, laminated nonburrow clay facies, and white-brown clay facies. The identified facies and SiO_2/Al_2O_3 and TiO_2/Al_2O_3 ratios indicated a continental depositional environment. The presence and high concentrations of non-clay-based minerals such as quartz, orthoclase, albites and muscovite and the complete absence of illite and montmorillonite clay minerals represent deposition under a continental environment from granitic rocks. The lower values of muscovite, albite, and orthoclase reflect deposition under humid paleoclimatic conditions with relatively low pH values. The high concentration of muscovite suggests that the clay sediments in the study area have undergone intense chemical weathering. This results in residual minerals within the studied clay formation. The cross plot of TiO_2 vs Al_2O_3, the high Ba/Co, Ni/Co, Ti/Zr, Mg/Ca and Si/Al ratios confirmed a mature felsic provenance with minor contributions from the mafic region.*

Keywords: *Clay; sedimentological; major oxide; depositional environments; provenance; trace elements*

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1.0 Introduction

Clay and claystone are fine-grained sedimentary materials occurring in both unlithified and lithified forms and are composed predominantly of particles within the clay-size fraction, as defined by the classical grain-size classifications of Udden (1898) and Wentworth (1922). Beyond particle size, clay is commonly described as a largely inorganic sedimentary material, excluding peat, muck, and organic-rich soils, and is dominated by aluminosilicate minerals derived from the weathering of pre-existing rocks (Kumari & Mohan, 2021). Mineralogically, clay minerals bear close structural and chemical resemblance to micas, reflecting their shared phyllosilicate framework (Klein & Hurlbut, 1985; Kumari & Mohan, 2021). They are characteristically plastic when wet (Andrade *et al*., 2011), harden upon firing at high temperatures of approximately 1200–1250 °C (Karaman *et al*., 2006), and consist mainly of layered tetrahedral and octahedral silicate sheets (Nadeau, 1984; Haydn, 2006; Ekosse, 2011; Odewumi & Adekeye, 2020). The wide industrial and economic importance of clay materials is largely controlled by their physical and chemical properties. Variations in grain size, platy morphology, brightness, inertness, and non-toxicity, together with chemical attributes such as electron donor–acceptor behavior (Solomon, 1968), swelling characteristics (Seed *et al*., 1966; Taylor & Smith, 1986), low permeability and adsorptive capacity (Giese & Van Oss, 2002; Mana *et al*., 2017), and high ion- and cation-exchange capacities (Gillott, 2012), make clays suitable for diverse applications ranging from ceramics and construction materials to environmental and industrial uses (Panjaitan, 2014). These properties are fundamentally linked to the mineralogical composition and geochemical evolution of the clay deposits. Clay minerals are formed primarily through the physical and chemical weathering of feldspars, micas, and other silicate minerals in parent rocks, followed by transport and deposition of the weathered products and subsequent diagenetic processes such as compaction, cementation, dissolution, recrystallization, and replacement (Haydn, 2006; Karaman *et al*., 2006; Kumari & Mohan, 2021). Because these processes are strongly influenced by source rock composition, climatic conditions, and depositional settings, clay mineral assemblages and bulk geochemistry provide valuable proxies for reconstructing sediment provenance, depositional environment, and paleoclimatic conditions. Among the geochemical indicators commonly employed in provenance studies, the TiO_2/Al_2O_3 and K_2O/Al_2O_3 ratios have been widely recognized as reliable discriminators of source rock composition and weathering intensity in fine-grained sediments (Cullers *et al*., 1987; Cullers, 1997; Ekosse, 2001, 2011; Agbongiague *et al*., 2024). This ratio reflects the relative immobility of titanium compared to aluminium during weathering and diagenesis, thereby preserving information about the nature of the parent rocks. The application of clay mineralogy and geochemical indices has been validated in stratigraphic correlation and paleoenvironmental reconstruction studies. For example, clay mineral assemblages have been successfully used in stratigraphic and paleogeographic reconstructions of Late Oligocene–Early Aquitanian sequences in the western internal southern Iberian margin, Spain (Alcara *et al*., 2013). Similarly, Dou *et al*. (2010) demonstrated the effectiveness of clay mineral and geochemical data in reconstructing sediment provenance and paleoenvironmental changes in the central Okinawa Trough. In addition, Mana *et al*. (2017) highlighted the relevance of clay mineral transformations and geochemical signatures in constraining temperature conditions associated with hydrocarbon generation from source rocks. Despite the extensive application of clay mineralogical and geochemical studies in sedimentary basins worldwide, detailed investigations integrating lithofacies analysis with mineralogical and geochemical proxies to interpret depositional environments, provenance, and paleoclimatic conditions remain limited in the present study area. In particular, such comprehensive studies have not been adequately undertaken for the Quaternary sedimentary clay deposits in Umukwata and its environs within the Niger Delta Basin, Nigeria. This study seeks to bridge this knowledge gap by integrating field-based sedimentological observations with mineralogical and geochemical analyses to elucidate the origin and depositional history of the clay deposits in the study area. Specifically, the study aims to determine the provenance and paleoclimatic conditions of the Quaternary clay formation using X-ray diffraction (XRD) and X-ray fluorescence (XRF) geochemical data, and to delineate the depositional environments through lithofacies characteristics and diagnostic geochemical ratios. The results are expected to contribute to a better understanding of Quaternary sedimentation processes in the Niger Delta Basin and to provide a robust framework for future sedimentological and paleoenvironmental studies in similar tropical deltaic settings.

This study provides a comprehensive mineralogical, geochemical, and sedimentological characterization of Quaternary clay deposits in the Niger Delta Basin, an area where detailed provenance, depositional environment, and paleoclimatic interpretations of clay formations are scarce. By integrating field-based lithofacies analysis with X-ray diffraction and geochemical proxies, the research improves understanding of sediment sources, weathering intensity, and paleoclimatic conditions that governed clay deposition in a tropical deltaic setting. The findings contribute to basin evolution models of the Niger Delta and provide reliable geochemical indicators useful for stratigraphic correlation and paleoenvironmental reconstruction in similar sedimentary basins.

In addition, the results offer baseline data relevant to industrial evaluation and sustainable utilization of clay resources for ceramics, construction materials, and other geotechnical applications. Overall, the study strengthens the application of clay mineralogy and geochemistry as robust tools in sedimentological, paleoenvironmental, and applied geological studies.

1.1 Location and geology of the study area

The sedimentary clay samples were picked up from Umukwata and its environs case study in the Ukwuani Local Government Area of Delta State, Nigeria.

The area is located in the Niger Delta Basin, southern Nigeria, within the latitudes 05º51-05º55 N and longitudes 06º09-06º15 E (Fig. 1). Several studies have been presented (Reyment, 1965; Short & Stauble, 1967; Weber, 1971; Weber & Daukoru, 1975; Avbovbo, 1978; Evamy *et al*., 1978; Doust & Omatsola, 1990; Nwajide, 2022; Ogbe *et al*., 2023; Ocheli *et al*., 2023; 2024; 2025). The Miocene-Recent Benin Formation, where the study area falls, is underlain by the Eocene-Recent paralic Agbada Formation, which comprises poorly to partially consolidated sands and gravels (Reyment 1965; Short & Stauble, 1967; Weber, 1971; Weber & Daukoru, 1975; Ocheli *et al*., 2023; 2024; 2025).

The Benin Formation is further underlain by the prodeltaic marine Akata Formation (Weber, 1971; Ogbe *et al*., 2020). These three subsurface formations of the Niger Delta Basin are considered diachronous (Evamy *et al*., 1978; Doust & Omatsola, 1990). The study deposit falls within the Quaternary period, Sambreiro, Warri deltaic plain deposits, sands (Allen, 1965a; b; Oseji & Ofomola, 2010; Ocheli *et al*., 2017; 2018; 2020). These are deep-seated and distributed into mangrove, wooded back swamps, fresh water swamps, and meandering belt wetlands. The study area is of a tropical rainforest characterized by tall trees, herbs, and shrubs, rainy and dry seasons and undulating terrains. Access to the exposed clay locations was achieved mainly by major tarred roads such as Umukwata-Ogume road, Eziokpor-Umukwata roads, unpaved roads, and foot tracks. The traversal was successful through the minor footpaths in the bushes where the sedimentary clay deposits were exposed.

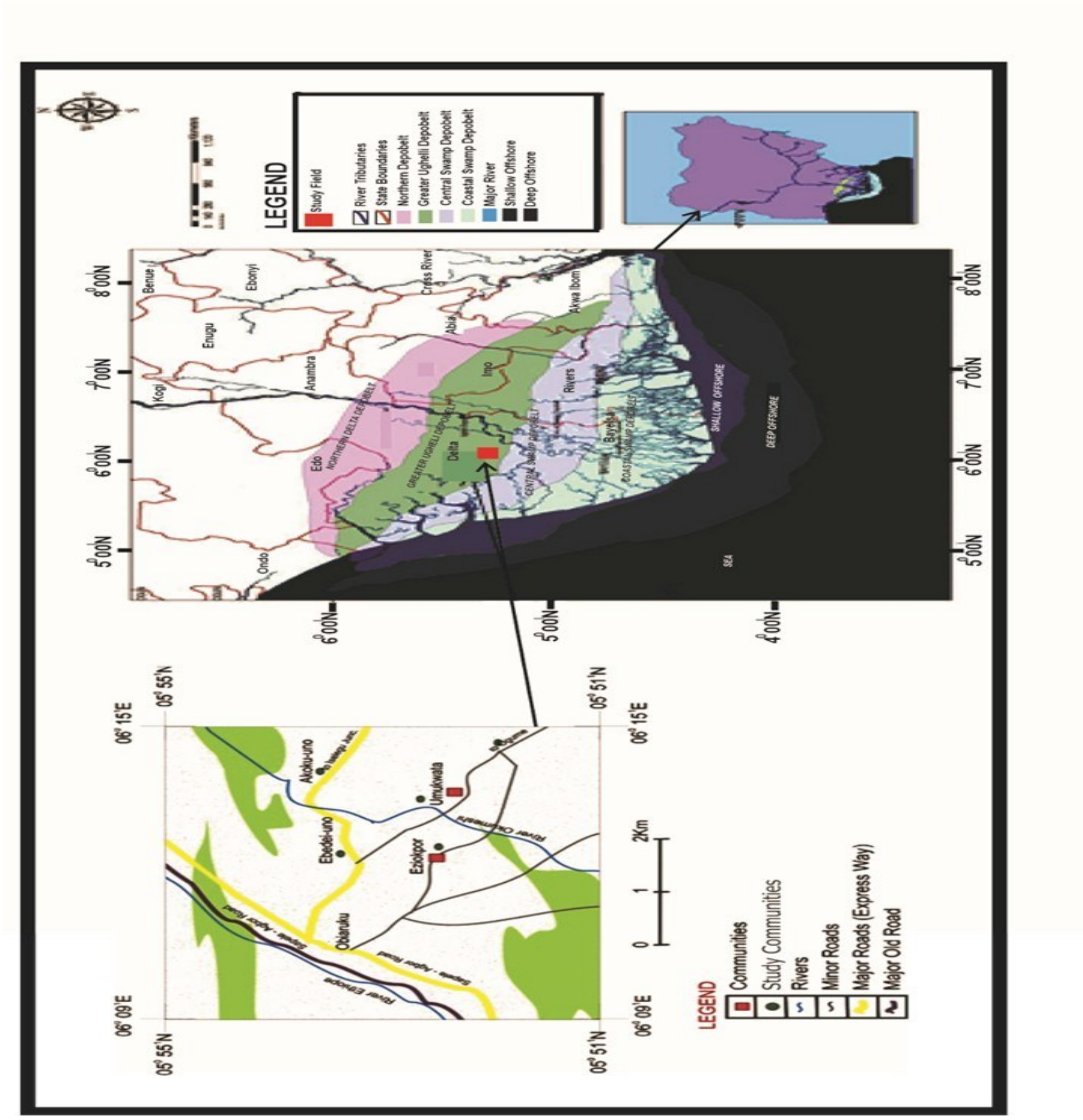

Fig. 1: Map showing the location of the study area (Ocheli *et al*., 2020) and map of the Niger Delta Basin, Nigeria, showing the study area and depobelts (Stacher, 1995; Ukpabi *et al*., 2014).

2.0 Materials and methods

2.1 Field studies and sample collection

Systematic and thorough inspection and geologic field mapping were conducted along the major roadcuts, river channels, footpaths, and quarry sites where sedimentary clay deposits are exposed within Umukwata and Eziokpor communities in Ukwuani Local Government Area, Delta State, Nigeria. Observations on the colour and texture of the clay materials were critically examined. The thickness of the clay beds was measured with the aid of a measuring tape. The geographical coordinates and elevation were measured using the Global Positioning System of the Garmin GPS Map 785 model. 20 clay samples were collected using an auger sampler at different depths and horizons from the topmost part of the profile to the base. The collected sedimentary clay samples were stored in an airtight nylon bag and well labelled to avoid confusion.

2.2 Laboratory analyses

The Clay samples were divided and subjected to X-ray diffraction (XRD) and inductively coupled plasma-mass spectrometry (ICP-MS) analyses to determine their mineralogical compositions, geochemical major oxides and trace element concentrations.

3.0 Results and discussion

3.1 Results of Field Studies

Field observations of the sedimentary clay deposits were systematically documented at selected locations within Umukwata and Eziokpor communities in Ukwuani Local Government Area, Delta State, Nigeria. For each location, lithology, colour, sedimentary structures, thickness, and biogenic features were recorded and used to infer depositional facies and environments.

3.1.1 Location 1: Owena, Umukwata Village

Location 1 is situated at Owena in Umukwata village, east of the north–south-trending Okumeshi River and approximately 270 m from the Umukwata–Ogume Road. The site lies at latitude 05°05′31.1″ N and longitude 06°01′13.3″ E, with an elevation of about 19.5 m above sea level. The exposed section has an approximate thickness of 6.8 m. The succession comprises alternating beds of silty clay with colour variations ranging from white and white-brown to brown. Plant remains occur sporadically within some horizons. The clay beds are generally laminated, and in several portions of the exposure, well-developed burrow structures are present (Fig. 2). The occurrence of bioturbation indicates deposition under conditions of adequate oxygenation and favourable salinity that supported biological activity. Based on lithology, sedimentary structures, and biogenic features, the clay deposits at this location are interpreted as laminated burrow-clay facies deposited in a low-energy, ponded depositional environment.

3.1.2 Location 2: Pond Site, Umukwata

Location 2 is located within a ponded area in Umukwata town, at some distance from the Umukwata–Ogume Road. The site is situated at a latitude of 05°04′48.1″ N and a longitude of 06°01′51.1″ E, with an elevation of approximately 19 m above sea level. The exposed clay deposits consist predominantly of fine-grained, whitish to light-brown clay units that are locally laminated (Fig. 3). In some areas, the deposits form channel-like bodies several metres wide, characterized by internal lamination and uniform grain size. Portions of the site are permanently waterlogged and host abundant burrowing organisms, including insects, worms, and crustaceans. The colour variations observed within the clay deposits range from red and brown to yellow, suggesting varying oxidation conditions during and after deposition. The presence of fine lamination, channel-like geometries, and active bioturbation indicates deposition in a shallow, low-energy, water-saturated environment. These features are characteristic of laminated non-burrowed to weakly burrowed clay facies formed in ponded or abandoned channel settings within a floodplain environment. The grey to blue colours observed revealed poorly oxygenated waterlogged areas. The clay formations at the studied location represent burrow and nonburrow clay facies that have been transported by river and deposited in floodplains under a low energy regime, delta plains including swamps, marshes and interdisciplinary bays. The depositional environment is considered continental.

3.1.3 Location 3: Eziokpor Area

Location 3 is situated within the Eziokpor area of Ukwuani Local Government Area, along Eziokpor-Umukwatata Road. The exposure occurs along a minor footpath where sedimentary clay deposits are well exposed. The site lies at an average elevation of approximately 20 m above sea level. This site lies at latitude $005^{0}47^{1}52^{11}$ N and longitude $006^{0}12^{1}52^{11}$ E. The clay sequence at this location is dominated by massive to weakly laminated clay beds with thicknesses varying between individual horizons. The clay units are predominantly white to greyish-brown in colour and are fine-grained, with occasional silty intercalations. Biogenic structures are rare or absent, and plant fragments (Fig. 4) are minimal. The massive nature of the clay beds, coupled with the absence of significant bioturbation, suggests deposition under relatively quiet, stagnant conditions with limited biological activity.

These characteristics are consistent with massive clay facies deposited in a low-energy, poorly oxygenated pond or back-swamp environment. Based on lithology, colour, sedimentary structures, and biogenic features, three principal clay facies were identified in the study area:

(i) laminated burrow-clay facies,

(ii) laminated non-burrowed to weakly burrowed clay facies, and

(iii) massive clay facies.

These facies collectively indicate deposition within low-energy continental settings dominated by ponded water bodies, abandoned channels, and back-swamp environments, typical of Quaternary floodplain and deltaic plain systems in the Niger Delta Basin.

The X-ray diffraction (XRD) patterns of representative claystone samples from the study area are presented in Figs. 5 and 6. The diffractograms reveal that the claystones are dominated by non-clay silicate minerals, with an average mineralogical composition of approximately 55.0% quartz, 21.0% albite, 17.0% orthoclase, and 7.0% muscovite. Clay minerals occur in subordinate proportions relative to the non-clay fraction. The dominance of quartz reflects its high chemical stability and resistance to chemical weathering during prolonged transport and sedimentary recycling. Similar quartz enrichment has been reported in continental clay deposits of the Anambra Basin (Alege *et al*., 2014) and Upper Benue Trough (Ocheli *et al*., 2018), where repeated erosion–deposition cycles preferentially remove less stable minerals.

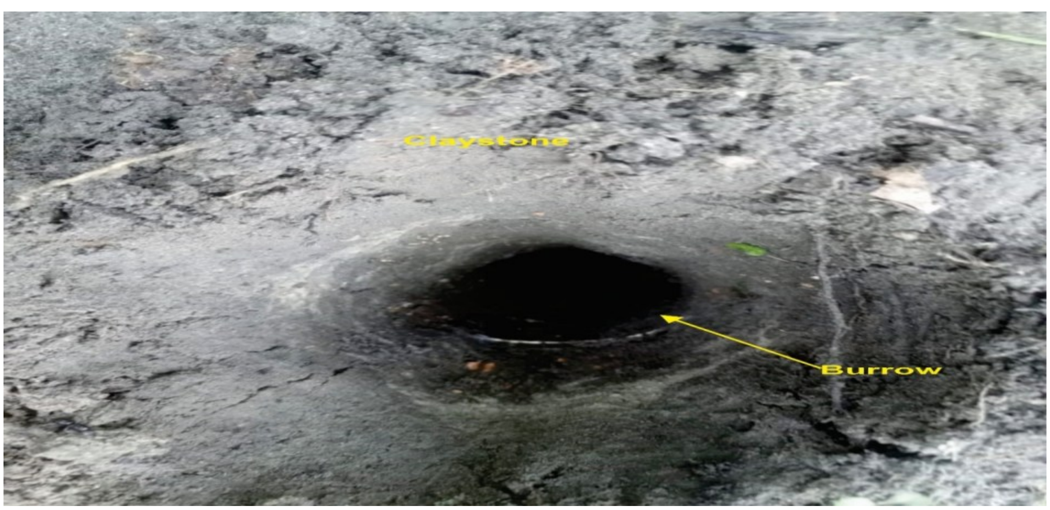

Fig. 2: Burrow observed in the claystone at location 1, Owena in Umukwata village, which is located east of the North-south stretch of the Okumeshi River. 2.7 m away from Umukwata-Ogume Road, Umukwata

Fig. 3: clay deposits in a pond situated in Umukwata town, some distance away from the Umukwata-Ogume road, Umukwata.

3.2 Mineralogical Composition (XRD Results)

The presence of albite and orthoclase suggests incomplete alteration of feldspars, although their relatively low proportions compared to quartz indicate advanced chemical weathering under humid conditions. Muscovite, which is more resistant than feldspars but less stable than quartz, occurs in minor amounts, implying prolonged exposure to weathering but limited mechanical breakdown

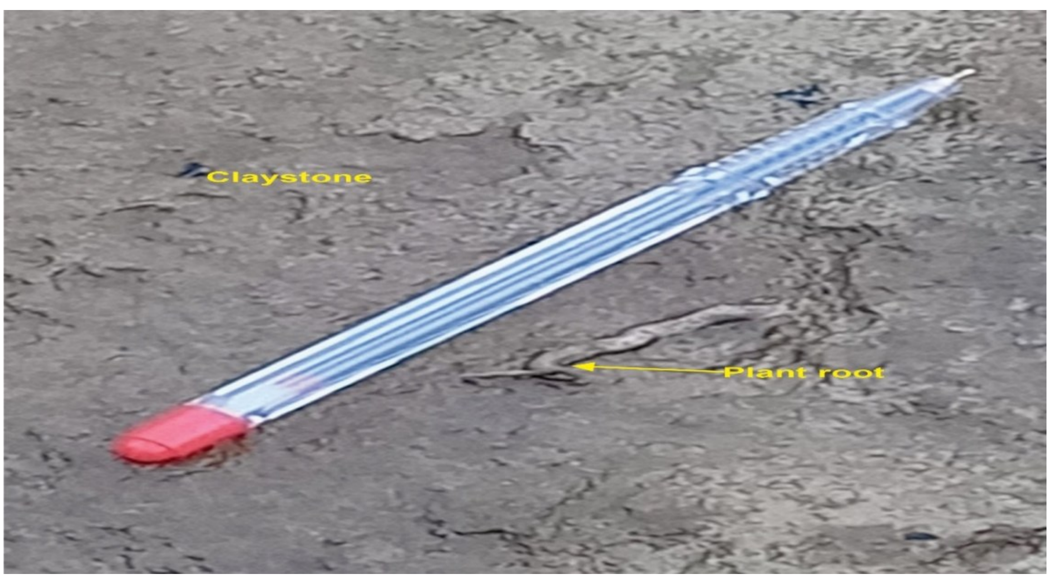

Fig. 4: Claystone with plant root near the Okumeshi River at the southern Outskirts.

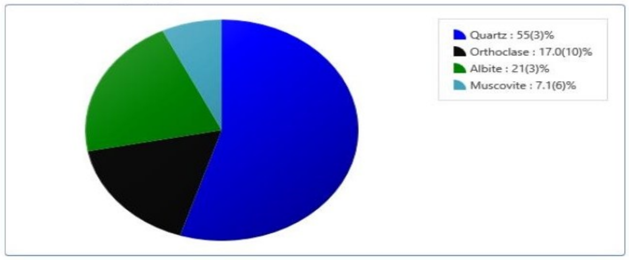

Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz	Orthoclase	Albite	Muscovite
Z4_20241224_124337_G01_S01_M01	0	55(3)	17.0(10)	21(3)	7.1(6)

Fig. 5: X-ray diffractogram for claystones in the study area.

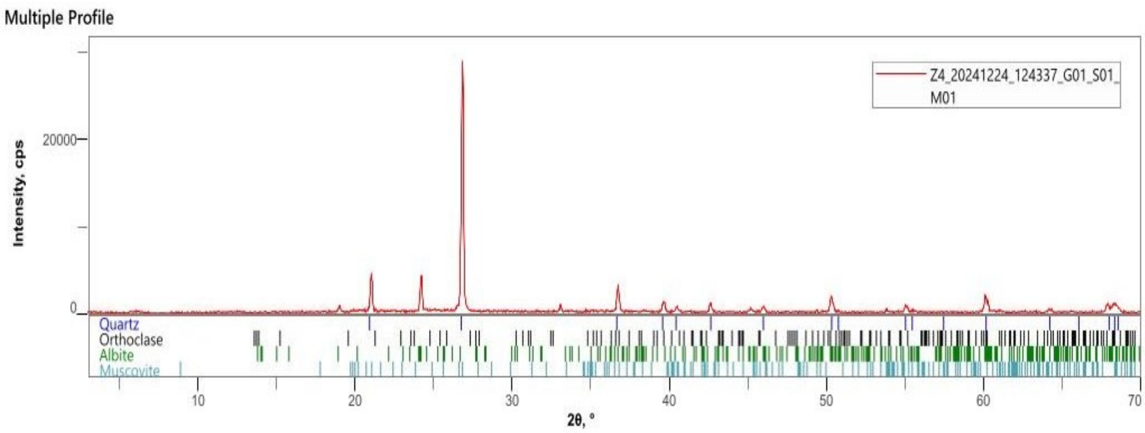

Fig. 6: Graphical representation of the mineral composition in the claystone samples in the study area.

The absence or near absence of marine-associated clay minerals such as illite and smectite (mtmorillonite) further suggests that the claystones were deposited in a continental rather than marine environment. This mineralogical assemblage is consistent with derivation from felsic to intermediate crystalline rocks, particularly granites and granodiorites, followed by intense chemical weathering and sedimentary recycling.

3.3 Major Oxide Geochemistry

The average major oxide composition of the twenty (20) clay samples obtained from X-ray fluorescence (XRF) analysis is presented in Table 1. The samples are characterized by high SiO_2 (79.34%) and Al_2O_3 (10.26%) contents, with subordinate Fe_2O_3 (2.26%), MgO (3.01%), CaO (1.62%), and TiO_2 (1.05%).

The dominance of SiO_2 reflects the abundance of quartz identified in the XRD analysis and suggests high sediment maturity. High SiO_2 values in claystones are commonly associated with prolonged chemical weathering, sedimentary recycling, and deposition in low-energy continental environments (Taylor & McLennan, 1985; McLennan, 2001; Cullers, 2002). The moderate Al_2O_3 content indicates the presence of aluminosilicate phases derived from feldspar alteration and residual clay minerals.

The SiO_2/Al_2O_3 ratio averages 7.73, which is significantly higher than values typical of immature sediments (<3) and mixed sediments (3–5). Such high ratios are indicative of quartz-rich, compositionally mature sediments commonly deposited in fluvial floodplain, deltaic, or shallow lacustrine environments (Bhatia, 1983; Bhatia and Crook, 1986; Roser and Korsch, 1986). Comparable ratios have been reported for continental clay deposits in southern Nigeria

(Alege *et al*., 2014; Odewumi and Adekeye, 2020). Moderate Fe_2O_3 contents suggest contributions from iron-bearing silicates and oxides, likely derived from weathered crystalline basement rocks. The relatively low CaO and MgO contents indicate minimal contributions from carbonate rocks or mafic source lithologies, further supporting a dominantly felsic provenance.

Table 1: The average composition of the major oxides in the 20 clay samples from the study area from the results of the XRF analysis.

Component	Average concentration values (%)	Average error (%)	Average moles values (%)	Average error (%)
SiO_2	79.340	1.979	82.924	2.069
V_2O_5	0.045	0.015	0.016	0.005
Cr_2O_3	0.096	0.010	0.040	0.004
MnO	0.024	0.006	0.021	0.005
Fe_2O_3	2.255	0.031	0.887	0.012
CoO	0.013	0.009	0.011	0.008
NiO	0.002	0.005	0.002	0.004
CuO	0.047	0.005	0.037	0.004
Nb_2O_5	0.013	0.006	0.003	0.001
WO_3	0.000	0.000	0.000	0.000
P_20_5	0.388	0.571	0.172	0.253
SO_3	0.200	0.101	0.157	0.080
CaO	1.617	0.073	1.810	0.081
MgO	3.010	10.471	4.689	16.315
K_2O	0.457	0.058	0.305	0.038
BaO	0.055	0.098	0.023	0.040
Al_2O_3	10.259	3.637	6.318	2.240
Ta_2O_5	0.046	0.017	0.007	0.002
TiO_2	1.051	0.039	0.827	0.030
ZnO	0.001	0.003	0.001	0.003
Ag_2O	0.011	0.037	0.003	0.010
Cl	0.953	0.074	1.689	0.131
ZrO_2	0.114	0.007	0.058	0.004
SnO_2	0.000	0.000	0.000	0.000
TiO_2/Al_2O_3	0.102	0.011	0.131	0.013
K_2O/Al_2O_3	0.045	0.016	0.016	0.017
Fe_2O_3/TiO_2	2.146	0.795	1.073	0.400
SiO_2/Al_2O_3	7.734	0.544	13.125	0.923
Al_2O_3/TiO_2	9.761	93.256	7.640	74.657

3.4 Trace Element Geochemistry

The average trace and elemental concentrations of the clay samples are presented in Table 2. The samples show high Si (37.09%) and O (50.37%) contents, moderate Al (5.43%), and low concentrations of Mg (1.82%), Ca (1.16%), Fe (1.58%), Ni (0.002%), Co (0.010%), and Cr (0.066%).

High Si and moderate Al concentrations confirm the dominance of quartz and aluminosilicate minerals, while low Ni, Co, and Cr concentrations indicate minimal mafic or ultramafic input. According to Wronkiewicz & Condie (1987, 1989), felsic source rocks are typically enriched in Si, Al, Ba, and Zr, whereas mafic rocks are enriched in Ni, Co, Cr, Mg, and Ti. The elemental distribution observed in the study area, therefore, supports a felsic-dominated provenance. Elemental ratios commonly used in provenance studies further support this interpretation.

Table 2: The average compositional values in the trace elements of 20 clay samples from the results of the XRF analysis study area.

Component	Average value of the intensity (c/s)	Average error (c/s)	Average concentration (%)
O	0.000	0.0000	50.370
Mg	1.034	3.5963	1.815
Al	34.306	12.1608	5.430
Si	1159.224	28.9202	37.087
P	9.666	14.2417	0.169
S	8.950	4.5377	0.080
Cl	142.581	11.1033	0.953
K	88.066	11.1052	0.379
Ca	412.470	18.5535	1.155
Ti	495.622	18.2303	0.630
V	27.421	8.8074	0.025
Cr	90.638	9.9166	0.066
Mn	32.398	8.2105	0.019
Fe	3354.585	46.2355	1.578
Co	25.576	18.0033	0.010
Ni	4.950	10.4972	0.002
Cu	121.339	12.1371	0.038
Zn	3.887	9.4716	0.001
Zr	275.921	17.3153	0.085
Nb	26.791	12.0058	0.009
Ag	2.896	9.4933	0.010
Sn	0.000	15.1520	0.000
Ba	9.640	16.9719	0.050
Ta	33.207	12.5022	0.037
W	0.000	12.4494	0.000
Ba/Co	0.377	0.9427	5.000
Ni/Co	0.194	0.5831	0.200
Ti/Zr	1.796	1.0528	7.412
Mg/Ca	0.003	0.1938	1.571
Si/Al	33.791	2.3782	6..830
Cr/Zr	0.3285	0.5727	0.777

The Ba/Co ratio averages 5.0, which exceeds the threshold (>4) indicative of felsic source rocks such as granites and rhyolites (Taylor and McLennan, 1985; Roser and Korsch, 1988). The Ni/Co ratio of 0.20 is characteristic of felsic to intermediate sources, while the low Ti/Zr ratio (7.41) suggests zircon enrichment through sedimentary recycling and derivation from felsic parent rocks.

3.5 Depositional Environment

Field observations, mineralogical data, and geochemical signatures collectively indicate deposition in a continental environment. Laminated clay facies, burrowed and non-burrowed clay units, variegated colours, and the presence of plant debris (Fig. 4) suggest deposition in low-energy settings such as floodplains, abandoned channels, ponds, swamps, and shallow lakes. High SiO_2/Al_2O_3 ratios (>5) further indicate deposition of quartz-rich sediments typically associated with fluvial and deltaic systems (Bhatia, 1983; Bhatia, 1985; Cullers *et al*., 1997; Cullers, 2002). The absence of marine clay minerals, coupled with bioturbation features and plant remains, rules out deep-marine or fully marine depositional environments. Similar depositional interpretations have been reported for continental clay deposits in the Niger Delta hinterland and Anambra Basin (Alege *et al*., 2014; Ocheli *et al*., 2017).

3.6 Provenance

The provenance of the claystones was evaluated using major oxide and trace element ratios. The average Al_2O_3/TiO_2 ratio of 9.76 falls within the range typical of intermediate igneous rocks (8–21), such as andesites and diorites (Hayasali *et al*., 1997; Ocheli *et al*., 2018; Armstrong-Altrin *et al*., 2024). However, the low TiO_2/Al_2O_3 ratio (0.102) and high SiO_2/Al_2O_3 ratio (7.73) are characteristic of felsic sources, particularly granites and rhyolites. The Fe_2O_3/TiO_2 ratio of 2.15 supports a felsic to intermediate provenance, while the low K_2O/Al_2O_3 ratio (0.045) suggests depletion of potassium during intense chemical weathering rather than an inherently K-rich granitic source. This pattern is consistent with derivation from weathered felsic to intermediate basement rocks, followed by sedimentary recycling. The cross plot of TiO_2 vs Al_2O_3 supported the findings that the parent source materials for the studied clay samples are derived from felsic-dominated source rock with slight intermediate derivatives (Fig. 7).

In this work, the provenance is interpreted as dominantly felsic, derived from granitic and high-grade metamorphic basement rocks, with minor intermediate and negligible mafic contributions. This interpretation is consistent with regional basement geology and comparable studies in southern Nigeria (Ekosse, 2001; Nyakairu & Koeberl, 2001; Odewumi and Adekeye, 2020).

3.7 Degree of Weathering, Sediment Maturity, and Paleoclimate

The low abundance of feldspars, particularly orthoclase, suggests advanced chemical weathering and leaching of alkali elements under humid conditions. High SiO_2/Al_2O_3 and Si/Al ratios indicate mature, quartz-rich sediments formed through prolonged weathering and recycling. The presence of zircon (high Zr content) further supports sediment maturity, as zircon is a highly resistant heavy mineral that accumulates during repeated sedimentary cycles. Low concentrations of Ni, Co, and Cr, coupled with moderate Fe contents, are indicative of intense chemical weathering typical of warm and humid tropical climates (Medard, 2000)

Such climatic conditions promote leaching of mobile elements and enrichment of resistant phases such as quartz and zircon. Collectively, the mineralogical and geochemical evidence indicates that the claystones formed under warm, humid paleoclimatic conditions, consistent with prolonged continental weathering in a low-relief cratonic setting. The integrated mineralogical, geochemical, and field evidence demonstrates that the claystones of the study area were deposited in continental low-energy environments, derived predominantly from intensely weathered felsic to intermediate basement rocks, and subjected to strong chemical weathering under humid tropical paleoclimatic conditions.

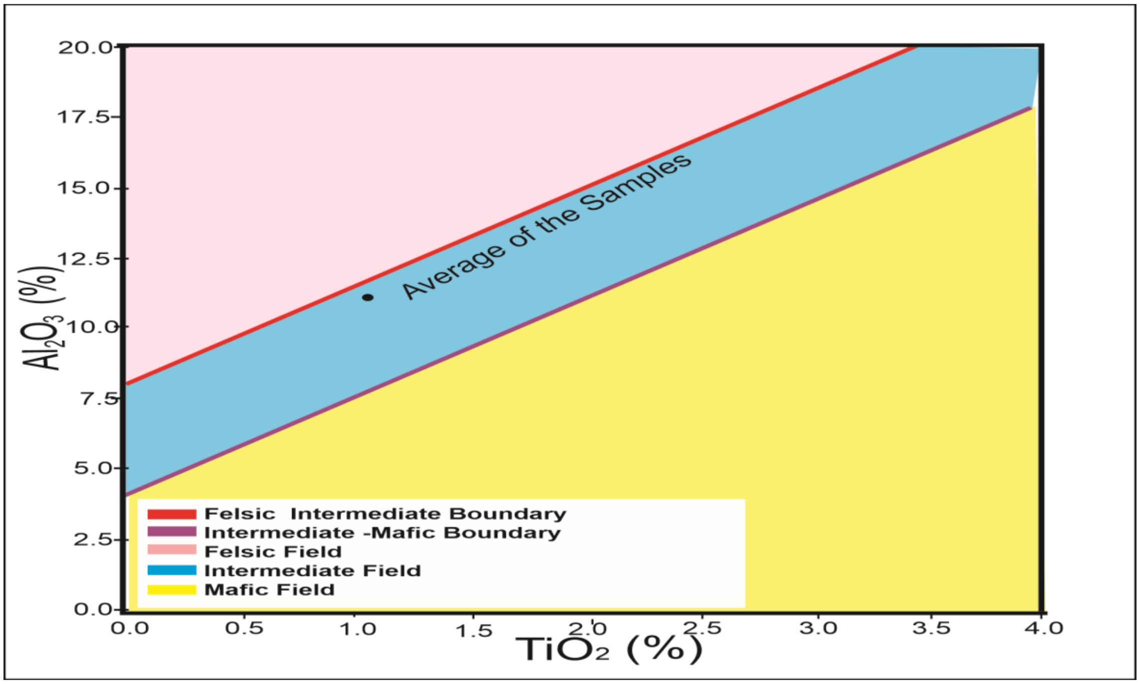

Fig. 7: Binary plot of Al_2O_3 versus TiO_2 of the average of 20 samples in the study area

4.0 Conclusion

The sedimentological characteristics and mineralogical major oxide, and trace element compositions in the onshore Niger Delta Basin, Nigeria where determined via field studies, X-ray diffraction (XRD) mineralogical methods and inductively coupled plasma-mass spectrometry (ICP-MS). Field studies revealed that the clay formation in the study area comprises of laminated, burrow clay facies, laminated nonburrow clay facies, and white-brown clay facies in a continental environment. The low TiO_2/Al_2O_3 and high Al_2O_3/TiO_2, Fe_2O_3/TiO_2, and SiO_2/Al_2O_3 ratios from the studied clay formation indicate that the sediments originated from intensely chemically weathered granitic or rhyolitic source areas or high-grade metamorphic rocks with felsic compositions such as gniesses with minor mafic contributions. The plot of TiO2 vs Al2O3 supported feslci dominated source rock with minor contributions from the mafic source rock derivatives. The Ba/Co, Ni/Co, Ti/Zr, Mg/Ca and Si/Al ratios confirmed a mature felsic provenance with minor contributions from the mafic region. The continental stratigraphic packages described in the study area were deposited under humid paleoclimatic conditions with relatively low pH values, and sedimentary clays have undergone intense chemical weathering.

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A.O. conceived and designed the study, conducted field sampling and lithofacies analysis, performed XRD and ICP-MS data interpretation, and drafted the manuscript. G.O.A. supervised the research, contributed to geochemical interpretation and provenance modeling, reviewed relevant literature, and critically revised the manuscript for intellectual content. Both authors approved the final version for publication.