

Mineralogical And Geochemical Constraints On The Provenance And Weathering Of Late Quaternary Sediments From Magumeri, Nigerian Sector Of The Chad Basin

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Abstract

Late Quaternary sediments of the Chad Formation exposed around Magumeri in northeastern Nigeria were investigated to determine their mineralogical composition, provenance, weathering history, depositional environment, and economic potential. Thirteen representative sediment samples were analysed using X-ray diffraction (XRD) and X-ray fluorescence (XRF). Quartz (25.9–62%) dominates the detrital mineral assemblage, while feldspars (albite and orthoclase) collectively reach up to 60%. Clay minerals include kaolinite ($\leq 14.9\%$), illite ($\leq 11.6\%$), and smectite ($\leq 14.2\%$). Major oxide compositions are characterized by high SiO₂ (65.8–76.2 wt%), moderate Al₂O₃, elevated K₂O, and relatively low MgO and CaO contents. Chemical Index of Alteration (CIA) values indicate moderate chemical weathering of predominantly felsic source rocks under fluctuating sub-humid to humid paleoclimatic conditions. Provenance indicators, including QFL plots and geochemical discrimination diagrams, suggest that the sediments were derived mainly from Pan-African granitic–gneissic basement terranes with evidence of sediment recycling within a tectonically stable intracratonic basin. Mineralogical and geochemical characteristics also indicate potential industrial applications for glass and ceramic production. These findings provide insight into Late Quaternary sedimentation and paleoclimatic variability within the Chad Basin.

Keywords: *Chad Basin; Provenance; Clay minerals; Chemical Index of Alteration (CIA); Late Quaternary; Magumeri sediments*

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I. Introduction

Intracratonic basins preserve long-term records of crustal evolution and paleoclimate in tectonically stable settings. Provenance studies integrating mineralogical and geochemical data are particularly effective in distinguishing source lithologies, assessing sediment recycling, and quantifying chemical weathering intensity (Dickinson, 1985; Taylor & McLennan, 1985).

The Chad Basin forms part of the West and Central African Rift System and originated during Early Cretaceous extensional tectonism associated with continental breakup (Fairhead, 1989; Genik, 1992). Syn-rift sedimentation was followed by prolonged post-rift thermal subsidence, resulting in thick continental successions. By the Late Cretaceous–Cenozoic, the basin evolved into a tectonically stable sag basin in which sedimentation was largely controlled by climate rather than tectonic rejuvenation (Genik, 1993).

The Chad Formation represents the youngest stratigraphic unit within the Nigerian sector of the basin. It comprises unconsolidated sands, silts, and clays deposited in fluvial and lacustrine environments during Late Pleistocene–Holocene hydrological oscillations linked to paleo-Lake Chad expansions and contractions (Drake & Bristow, 2006). Despite its hydrogeological importance, detailed mineralogical and geochemical studies of surface exposures in the Magumeri area remain limited.

This study integrates mineralogical and geochemical data to constrain provenance, weathering intensity, depositional conditions, and economic implications of Late Quaternary sediments within the broader tectono-sedimentary framework of the Chad Basin.

Geological Setting

The Nigerian sector of the Chad Basin (Figure 1) is bounded by Precambrian Pan-African basement complexes composed predominantly of granites, gneisses, and migmatites. Basin initiation during the Early Cretaceous (~145–100 Ma) generated fault-controlled depocenters (Genik, 1992). Subsequent thermal subsidence produced a broad intracratonic sag basin.

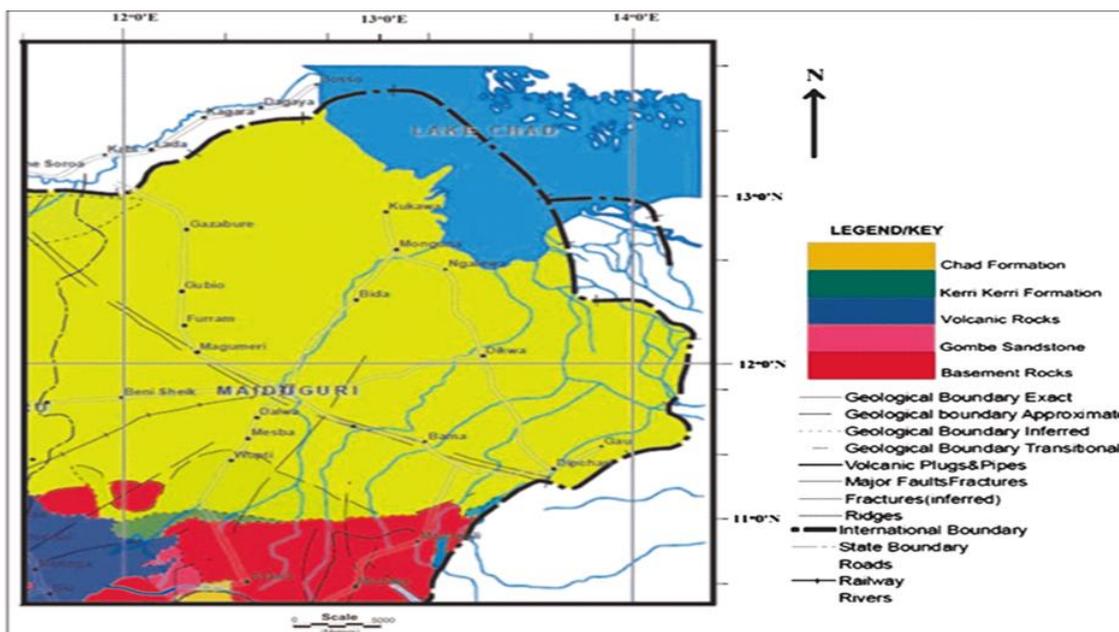


Figure 1. Geological setting of the Nigerian sector of the Chad Basin adapted from NGS (2006)

The stratigraphic succession of the Bornu Basin commences with the continental, feldspathic Bima Sandstone. This unit is overlain by the calcareous Gongila Formation, deposited during early marine transgression. The overlying Fika Shale consists predominantly of gypsiferous blue-grey shale interbedded with thin, discontinuous limestone layers (Okosun, 1995). Above the Fika Shale lies the Gombe Sandstone, composed of estuarine to deltaic sandstones, siltstones, and subordinate shales, locally containing coal seams and ferruginised horizons that form low-grade ironstones (Carter, 1963). The succession is capped by the Kerri-Kerri Formation, which comprises loosely consolidated sandstones, siltstones, and claystones with minor conglomerate and ironstone; these deposits are interpreted as lacustrine–deltaic and exceed 200 m in thickness. The youngest stratigraphic unit is the Chad Formation, characterized by yellow to grey clays, sands, sandy clays, and diatomite (Carter, 1963).

The Chad Formation forms the uppermost basin fill and consists of poorly consolidated sands, silts, and clays deposited in fluvial channels, floodplains, and lacustrine settings influenced by paleo-Lake Chad fluctuations. The Magumeri area represents part of this Late Quaternary depositional system (Figure 2)

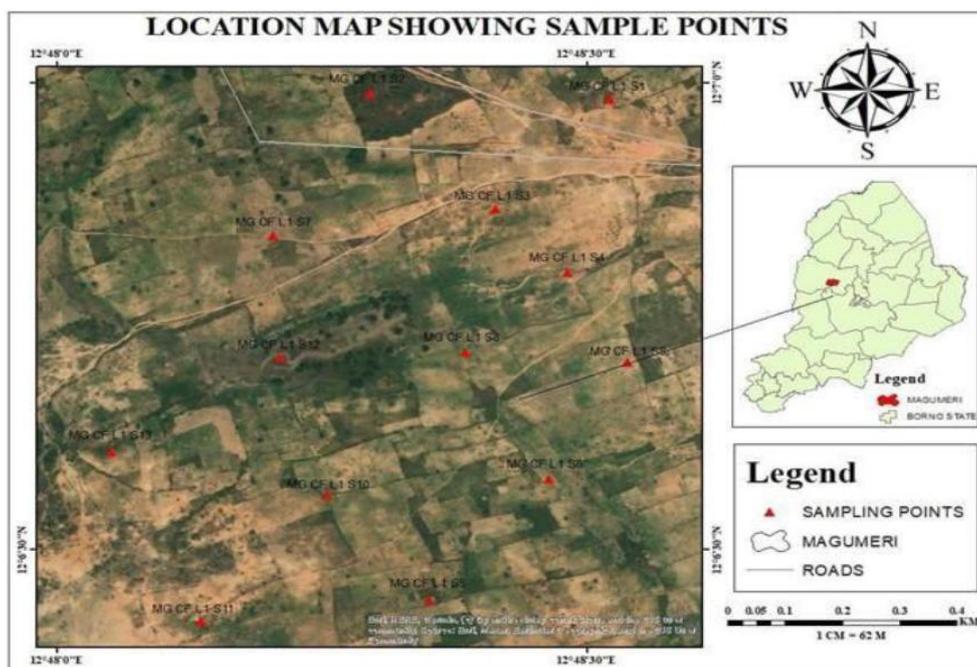


Figure 2. Location map of the study area

II. Materials And Methods

Thirteen fine-grained sediment samples were collected from surface exposures of the Chad Formation around Magumeri. Samples were air-dried, disaggregated, and sieved to <63 μm prior to analysis.

Mineralogical composition was determined using X-ray diffraction (XRD) with $\text{CuK}\alpha$ radiation. Semi-quantitative mineral proportions were estimated from peak intensities. Major oxide concentrations were measured using X-ray fluorescence (XRF) following standard fusion preparation procedures.

Chemical weathering intensity was assessed using the Chemical Index of Alteration (CIA) (Nesbitt & Young, 1982). Samples were plotted on an A–CN–K ternary diagram to evaluate weathering trends and feldspar alteration pathways.

III. Results

X-ray diffraction analysis of the thirteen sediment samples collected around Magumeri reveals a mineral assemblage dominated by quartz, kaolinite, illite, smectite (montmorillonite), albite, orthoclase, and muscovite (Table 1). Quartz ranges from 25.9% (MGCFL1S10) to 62% (MGCFL1S4), with most samples exceeding 40%. Feldspar content (albite + orthoclase) collectively ranges between 18% and 60%, Muscovite occurs in minor to moderate amounts (0.29–11.9%), with Quartz as the most abundant non-clay mineral phase across all samples. Representative diffractograms illustrating the mineral phases identified in the thirteen samples are presented in Figure 3.

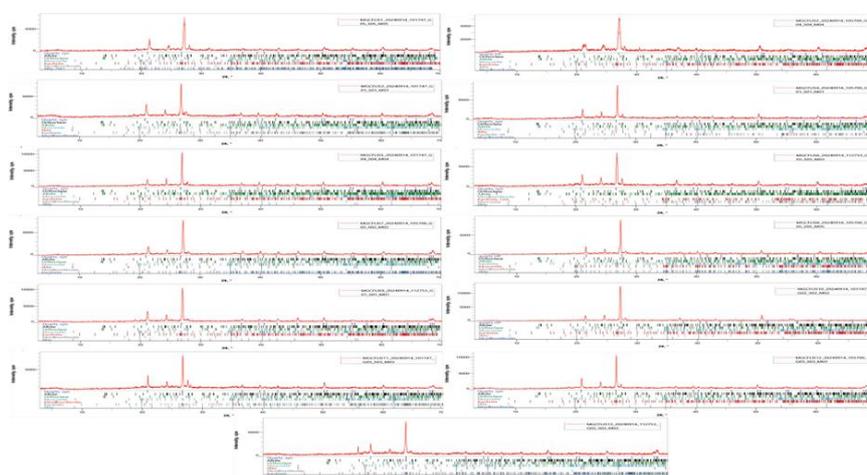


Figure 3. X-ray diffraction (XRD) diffractograms of representative sediment samples from Magumeri showing the dominant mineral phases including quartz, albite, orthoclase, muscovite, kaolinite, illite and smectite

The samples were also analysed for major oxides to determine their concentration across the area. Clay minerals show marked variability. Kaolinite ranges from trace values (<1%) to 14.9%, illite from trace to 11.6%, and montmorillonite from negligible amounts to 14.2%. The coexistence of kaolinite and smectite within several samples suggests mixed weathering regimes prior to deposition (Table 2). Silica is consistently high across all samples, exceeding 70 wt% in seven samples, confirming quartz enrichment. Al_2O_3 concentrations correlate broadly with clay mineral abundance. K_2O values are relatively elevated, showing significant feldspar and illite contributions. MgO and CaO occur in low concentrations, while TiO_2 values remain consistently between 1.62 and 2.16 wt%, suggesting a stable heavy mineral input.

TABLE 1. showing major oxide concentration of Clay (in wt%).

Sample ID	Fe2O3	SiO2	Al2O3	MgO	K2O	TiO2	CaO	P2O5	MnO	CIA
MGCFS1	6.0	72.8	11.4	0.081	4.5	1.9	1.09	1.62	0.059	62.42
MGCFS2	5.1	75.4	9.5	0.077	5.0	1.7	0.98	1.67	0.039	57.15
MGCFS3	8.0	69.5	11.0	0.082	5.5	2.1	1.38	1.68	0.073	56.46
MGCFS4	8.0	69.6	11.4	0.097	5.2	2.0	1.35	1.67	0.072	58.42
MGCFS5	8.2	70.0	11.4	0.114	4.9	1.8	1.40	1.68	0.056	59.32
MGCFS6	7.6	69.5	12.8	0.071	3.2	1.7	0.97	1.64	0.056	71.1
MGCFS7	4.8	76.2	8.6	0.033	5.7	1.6	1.00	1.60	0.046	51.99
MGCFS8	5.6	74.7	9.2	0.055	5.2	1.9	1.05	1.51	0.071	55.23
MGCFS9	6.5	73.3	11.0	0.042	4.4	1.8	0.55	1.65	0.039	65.88
MGCFS10	5.8	73.6	10.2	0.035	5.0	1.7	1.17	1.72	0.059	57.54
MGCFS11	11.5	65.8	11.5	0.039	5.0	2.2	1.51	1.77	0.093	58.57
MGCFS12	9.7	67.7	11.8	0.152	4.6	1.9	1.46	1.75	0.086	60.65
MGCFS13	10.0	67.1	12.1	0.080	4.5	2.0	1.49	1.74	0.096	61.38

TABLE 2. Showing the Mineralogical Composition of Clay (in %).

Sample ID	QUARTZ	ALBITE	ORTHOCLASE	MUSCOVITE	KAOLINITE	ILLITE	SMECTITE
MGCFS1	38.0	9.1	16.7	9.5	11.2	11.40	4.20
MGCFS2	39.0	12.0	13.3	7.1	14.9	10.30	3.00
MGCFS3	54.0	13.0	14.2	8.1	10.4	0.01	0.20
MGCFS4	62.0	9.1	14.9	7.2	0.9	0.01	6.00
MGCFS5	43.0	15.3	16.0	7.5	0.5	11.20	6.00
MGCFS6	55.2	18.6	8.6	0.7	0.2	11.60	5.03
MGCFS7	41.0	23.0	18.3	11.9	0.2	0.10	5.10
MGCFS8	46.0	4.0	37.0	2.3	8.8	2.30	0.01
MGCFS9	54.0	26.0	12.0	2.0	1.0	3.50	1.17
MGCFS10	25.9	23.0	24.5	6.6	11.8	1.90	5.70
MGCFS11	49.0	18.1	17.0	7.9	2.9	4.30	0.13
MGCFS12	32.0	23.6	21.9	1.8	11.4	9.00	0.01
MGCFS13	44.0	16.0	17.0	0.3	3.0	5.30	14.20

IV. Discussion

Chad Basin Framework and Stratigraphic Context

The studied sediments belong to the Chad Formation, the youngest stratigraphic unit within the Nigerian sector of the Chad Basin. The basin initiated during Early Cretaceous rifting (~145–100 Ma) associated with the West and Central African Rift System (Genik, 1992; Fairhead, 1988). Syn-rift clastic deposition was followed by prolonged post-rift thermal subsidence and intracratonic sag sedimentation throughout the Late Cretaceous and Cenozoic. The Chad Formation represents Late Pleistocene–Holocene (<2.6 Ma) lacustrine–fluvial sedimentation linked to paleo–Lake Chad fluctuations (Drake and Bristow, 2006). Therefore, the Magumeri sediments record the final stage of basin infill within a tectonically stable cratonic interior.

Mineralogical Maturity and Provenance

Quartz dominance (up to 62%) indicates a relatively high degree of mineralogical maturity, which is typical of sediments that have undergone prolonged transport and recycling within stable intracratonic settings (Dickinson, 1985). Such enrichment reflects the preferential survival of mechanically and chemically stable minerals during repeated erosion and deposition cycles since the Cretaceous rifting phase of the basin. The presence of significant feldspar components (albite and orthoclase, collectively reaching up to 60%) indicates continued contributions from felsic source rocks. This interpretation is further supported by the QFL provenance diagram (Figure 4), which shows that most samples plot within the recycled orogenic field.

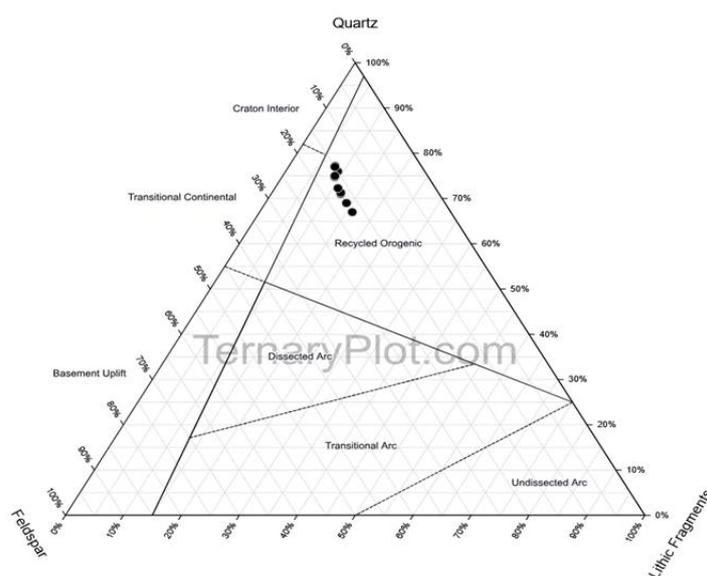


Figure 4. QFL ternary diagram showing the provenance classification of Magumeri Formation sandstones based on quartz (Q), feldspar (F), and lithic fragments (L) following Dickinson (1985). The samples plot mainly within the recycled orogenic field, indicating derivation from uplifted continental crust.

Muscovite occurrence also suggests derivation from Pan-African granitic–gneissic basement terranes that surround the Chad Basin (>600 Ma). Together, the mineralogical composition indicates that the sediments were derived predominantly from felsic continental sources with evidence of sediment recycling from older basin deposits.

Clay mineral assemblages provide important insights into the prevailing weathering conditions in the source region. Kaolinite formation typically requires intense hydrolytic weathering under humid, well-drained conditions (Chamley, 1989), whereas smectite formation is favoured in semi-arid environments characterized by moderate chemical alteration and restricted leaching (Weaver, 1989). The coexistence of these clay minerals suggests alternating humid and semi-arid weathering regimes prior to deposition. The coexistence of kaolinite and smectite in several samples therefore suggests alternating humid and semi-arid weathering regimes prior to deposition. Such mineralogical variability is consistent with Late Pleistocene–Holocene climatic oscillations associated with fluctuations of paleo-Lake Chad. (Drake & Bristow, 2006). These climatic variations likely controlled sediment supply, weathering intensity, and clay mineral transformation during the deposition of the Chad Formation. Overall, the sediments of the Chad Formation represent predominantly recycled felsic continental detritus derived from Precambrian basement rocks and deposited in low-energy fluvio-lacustrine environments within the Chad Basin

Geochemical Evidence for Upper Continental Crust Provenance

Major oxide geochemistry further constrains sediment provenance and compositional maturity. SiO₂ concentrations ranging from 65.8 to 76.2 wt% approach typical upper continental crust values (Taylor & McLennan, 1985), indicating a strong felsic contribution to the sediment supply. Low concentrations of MgO and CaO suggest minimal input from mafic or carbonate sources. In contrast, relatively elevated K₂O values (3.18–5.65 wt%) reflect significant contributions from K-bearing minerals such as K-feldspar and illite, which are characteristic of granitic and metamorphic source rocks. These geochemical relationships are consistent with the litharenite–wacke classification shown in the geochemical discrimination diagram (Figure 5). TiO₂ values (1.62–2.16 wt%) suggest stable heavy mineral input from felsic sources. Fe₂O₃ values up to 11.5 wt% likely reflect oxidation under subaerial or shallow lacustrine conditions rather than primary mafic input. Relationships between clay minerals and major oxides further illustrate mineral–chemical associations. Geochemical classification using the Herron diagram (Figure 5) indicates that the samples plot within the litharenite and wacke fields.”. The agreement between mineralogical composition, major element geochemistry, and provenance discrimination diagrams strongly supports derivation of the Magumeri sediments from felsic Pan-African basement rocks with evidence of sediment recycling within the Chad Basin.

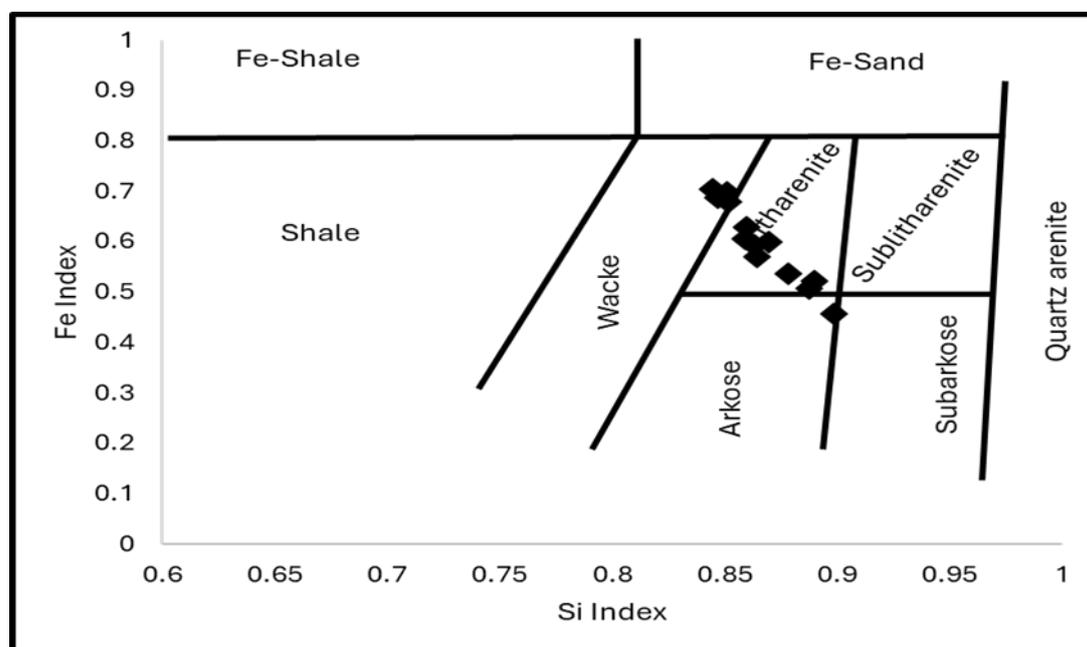


Figure 5. Geochemical classification of Magumeri Formation sandstones using the Herron (1988) diagram based on $\log(\text{SiO}_2/\text{Al}_2\text{O}_3)$ versus $\log(\text{Fe}_2\text{O}_3/\text{K}_2\text{O})$. The samples plot within the litharenite and wacke fields, suggesting moderate compositional maturity and derivation from felsic source rocks.

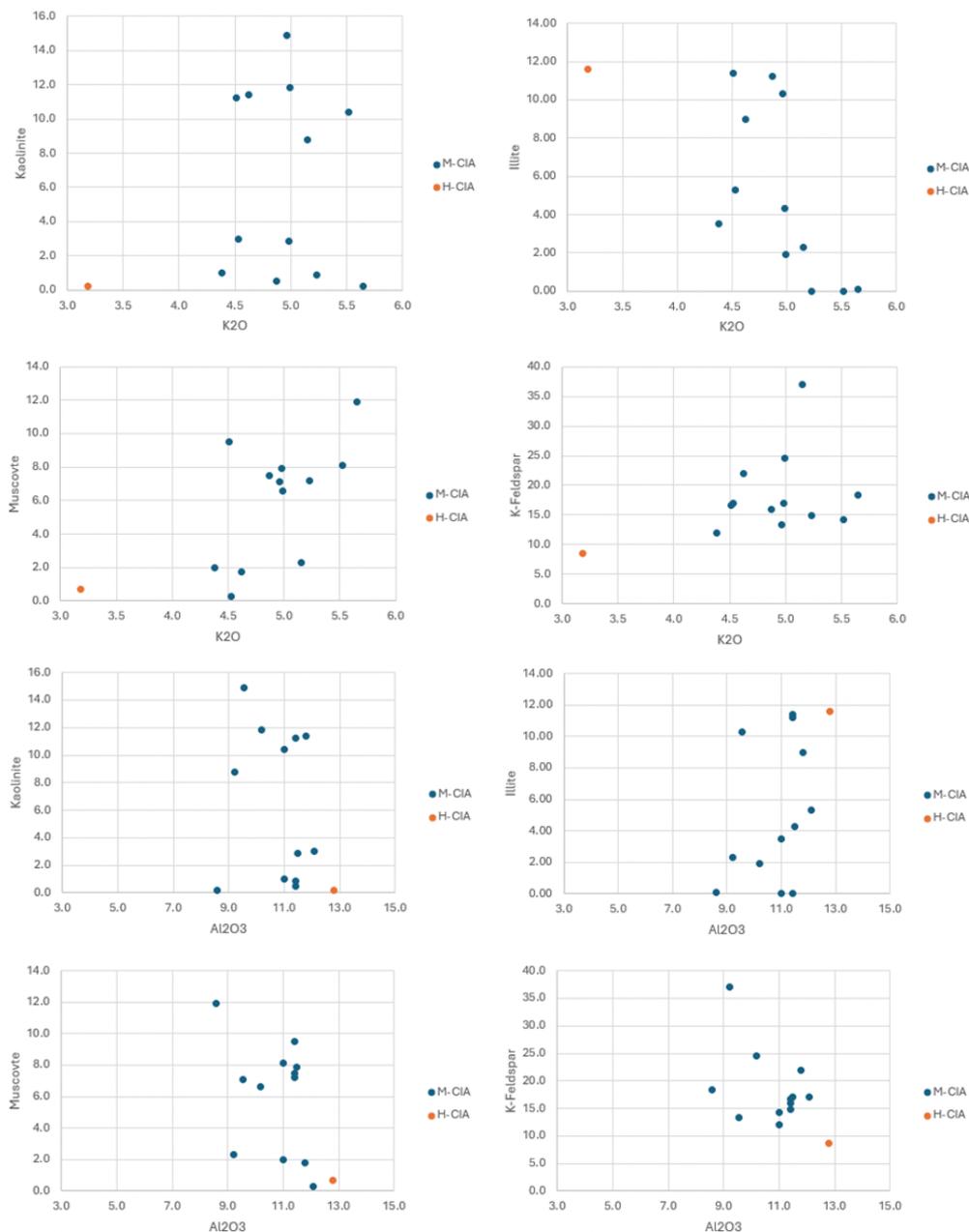


Figure 6. Bivariate plots showing relationships between mineral abundance and K₂O concentration: (A) kaolinite vs K₂O, (B) illite vs K₂O, (C) muscovite vs K₂O, and (D) K-feldspar vs K₂O.

Chemical weathering intensity in the Chad Formation was evaluated using the Chemical Index of Alteration (CIA) proposed by Nesbitt and Young (1982):

$$CIA = \left[\frac{Al_2O_3}{[Al_2O_3 + CaO^* + Na_2O + K_2O]} \right] \times 100$$

where CaO* represents CaO incorporated in silicate minerals only.

Based on the major oxide data, the calculated CIA values range from approximately 65 to 78, indicating moderate to relatively intense chemical weathering of the source rocks. These values suggest substantial feldspar alteration but incomplete removal of alkali and alkaline-earth elements, which is typical of weathering under sub-humid to humid climatic conditions. The weathering trend displayed on the A–CN–K diagram (Figure 7), shows progressive alteration of feldspar toward the Al₂O₃ apex, reflecting the transformation of feldspar into clay minerals during chemical weathering. (McLennan, 1993; Nesbitt & Young, 1982). However, the persistence of feldspar in the sediments indicates that weathering did not reach the extreme intensity associated with tropical lateralization, but rather occurred under fluctuating climatic regimes (Tardy, 1997).

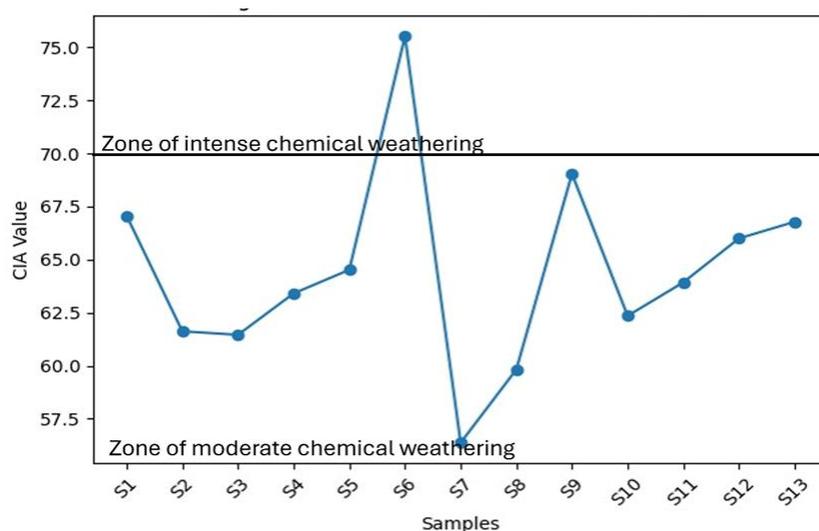


Figure 7. A–CN–K ternary diagram showing the Chemical Index of Alteration (CIA) trend for the Magumeri sediments, illustrating moderate chemical weathering and feldspar alteration towards the Al_2O_3 apex. after Nesbitt and Young (1982).

Mineralogical evidence further supports this interpretation. The coexistence of kaolinite and smectite provides important paleoclimatic constraints. Kaolinite typically forms under conditions of intense leaching and efficient drainage in humid environments (Chamley, 1989), whereas smectite is more stable in semi-arid settings characterized by moderate chemical alteration and restricted drainage (Millot, 2013). The presence of both clay minerals in the Chad Formation therefore indicates alternating humid and semi-arid phases during sediment generation and deposition.

These geochemical and mineralogical signatures are consistent with documented Late Quaternary hydrological oscillations within the Chad Basin, including expansions and contractions of paleo-Lake Chad (Drake & Bristow, 2006). Overall, the sediments of the Chad Formation record not only source rock composition but also paleoclimatic variability that influenced chemical weathering intensity, sediment supply, and clay mineral transformation during Late Quaternary basin evolution.

Depositional Environment and Basin Processes

Textural and mineralogical evidence suggests deposition in a low-energy lacustrine to fluvial environment. The fine-grained nature and clay dominance indicate deposition in low-energy lacustrine to distal floodplain environments associated with paleo-Lake Chad. During humid phases, increased fluvial discharge transported quartz and feldspar detritus from basement uplifts into the basin. During lacustrine highstands, suspension settling dominated. The uniform geochemical signature and high mineralogical maturity reflect sediment recycling in a tectonically quiescent intracratonic basin (Dickinson, 1985). Following Early Cretaceous rifting, the Chad Basin experienced long-term thermal subsidence without significant tectonic rejuvenation (Genik, 1992), allowing climate to become the dominant control on sedimentation. Early diagenesis appears minimal. Limited smectite-to-illite transformation suggests shallow burial and low thermal maturity consistent with Late Quaternary deposits.

Results integration

The integrated mineralogical, geochemical, and provenance discrimination results indicate that the Magumeri Formation sandstones were predominantly derived from felsic continental sources. The dominance of quartz and feldspar in the XRD analysis, together with high SiO_2 and K_2O concentrations, suggests derivation from granitic and gneissic rocks of the Pan-African basement complex surrounding the Chad Basin. Provenance discrimination diagrams such as the QFL and Herron plots further support a recycled orogenic provenance, indicating that the sediments were derived from uplifted continental crust and recycled sedimentary sequences.

Economic Significance

The compositional characteristics of the Magumeri sediments demonstrate considerable industrial potential. High silica content (>70 wt% in several samples) supports potential use in glass manufacturing. The silica–alumina framework is suitable for ceramic production, with K_2O acting as a natural flux. Smectite-rich samples exhibit swelling and adsorption properties useful for engineered liners and containment systems. Additionally, the relatively low MgO and CaO contents reduce the risk of excessive fluxing during high-

temperature processing, enhancing suitability for refractory applications. The moderate iron content may impart coloration, which can be advantageous for structural ceramic products such as bricks and tiles. However, from a sedimentological perspective, the primary significance of these sediments lies in their record of Late Quaternary climatic variability and intracratonic basin evolution

Thus, beyond their geological significance, the sediments represent economically viable industrial raw materials for northeastern Nigeria.

V. Conclusion

This study provides new mineralogical and geochemical insights into the Late Quaternary sediments of the Chad Formation around Magumeri in northeastern Nigeria. XRD results reveal that the sediments are dominated by quartz with significant feldspar and clay mineral components, indicating moderate mineralogical maturity. Major oxide geochemistry and provenance diagrams suggest that the sediments were derived primarily from felsic Pan-African basement rocks surrounding the Chad Basin, with evidence of sediment recycling from older basin deposits. Chemical Index of Alteration (CIA) values indicate moderate chemical weathering of source materials under fluctuating climatic conditions during the Late Quaternary. The coexistence of kaolinite and smectite further supports alternating humid and semi-arid paleoclimatic regimes linked to paleo-Lake Chad fluctuations. Sediment deposition occurred within low-energy fluvio-lacustrine environments in a tectonically stable intracratonic basin. In addition to their geological significance, the high silica and suitable mineralogical composition suggest that these sediments have potential industrial applications in glass and ceramic production.

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