INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue VIII August 2025

Geochemical Investigation of the Nanka Formation in Southeastern Nigeria: Proxy for Sediment Provenance and Tectonic Setting

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DOI: https://doi.org/10.51244/IJRSI.2025.120800206

Received: 12 Aug 2025; Accepted: 21 Aug 2025; Published: 20 September 2025

ABSTRACT

This study investigates the geochemical characteristics of the Nanka Formation in the Niger Delta Basin, southeastern Nigeria. The research was carried out in order to reconstruct it's sediment provenance, weathering history, depositional environment, and tectonic setting. Representative sandstone samples collected from the outcrop sections of the formation were analyzed for major and trace elements using X-ray Fluorescence (XRF) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) techniques. The results revealed that the major elements are dominated by silica with concentration value ranges of 72.95 and 82.14wt%. Comparison of the major and trace elements concentrations in the investigated sediment with the Upper Continental Crust (UCC) and Post-Archean Australian Shale (PAAS) indicated silica enrichment and depletion of Al2O3, CaO, MgO, K2O and Na2O. Trace elements such as Ni, Co, Zn, Th and Zr were depleted with respect to PAAS. There is also minor enrichment of U and Ba. The sandstones were classified as litharenites and sublitharenites. Geochemical indices such as the Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Chemical Index of Alteration (CIW) have value ranges of 46.94 to 57.94%, 55.28 to 74.02% and 50.77 to 66.61% respectively. The value ranges of the indices are consistent with A- CN- K tenery plot of the sandstone, suggesting moderate weathering. The Index of Compositional Variability (ICV) values of between 1.37 and 1.60% indicate immature source rock. The paleo- climatic condition is semi- humid. Nanka Formation is sourced from felsic and intermediate igneous rocks from passive margin and was deposited in a marginal marine setting.

Keywords: Geochemical, major elements, trace elements, depositional environment, Provenance.

INTRODUCTION

Awka and environs is underlain by the Imo and Nanka Formations, which are parts of the outcropping sedimentary units of the Niger Delta Basin (Nwajide, 1979, 1980). The preservation of clastic sediments provides comprehensive insights into the provenance, tectonic setting, paleo- weathering, paleo- climatic condition and depositional environments of such sedimentary units. According to Oghenekome *et al*. (2016), clastic sediments preserve detailed information on provenance and pattern in which the sediments were transported.

The geochemical composition of siliclastic sediments is influenced by various factors, which include the parent rock, relief, climate, sediment transport, deposition, and diagenetic processes. These factors have been found to have an impact on the sediment characteristics (Dickinson *et al.*, 1983; Dickinson, 1985, 1988; Basu, 1985). The utilization of geochemical signals in siliciclastic rocks has been employed to obtain insights into several aspects, including sediment classification, provenance, tectonic environment, weathering conditions, and paleo- climate (Roser and Korsch, 1988; Ahmad *et al.*, 2014; Ejeh *et al.*, 2015; Edegbai *et al.*, 2019; Overare *et al.*, 2020).

This paper investigates the geochemical signatures of the Nanka Formation as a means to reconstruct its provenance and infer its associated tectonic setting. The objectives of this study are to analyse the major and trace element composition, Identify the geochemical signatures, interpret weathering intensity and sediment

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maturity, reconstruct the tectonic setting, evaluate the depositional environment and compare the geochemical data with established global models.

The Study Area

The study area, Awka and environs is situated within latitudes 06º 10'0" N and 06º 15'0" N and longitudes 07º 0'0"E and 07º 5'30" E and underlain by the Imo Formation and the investigated sediments of the Nanka Formation (Fig. 1). The two formations are part of the outcropping Niger delta (Short and Stauble, 1967).

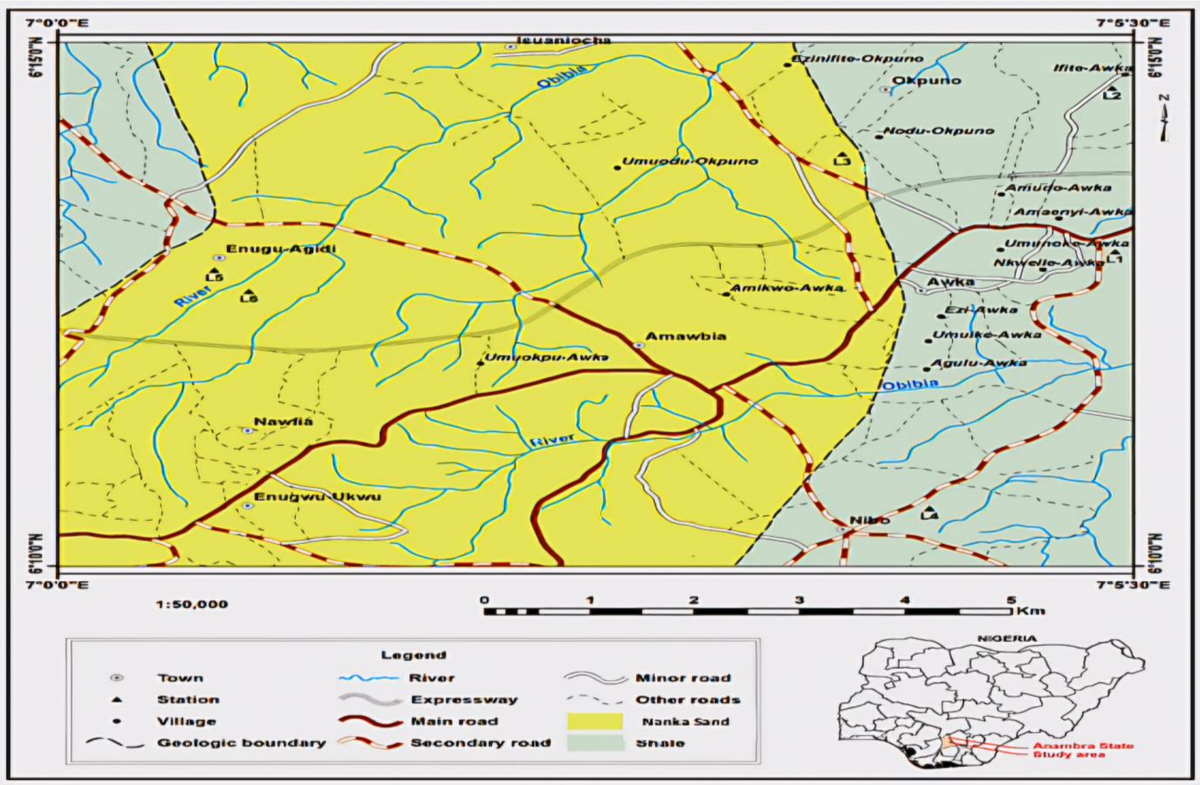

Fig. 1 Geologic map of the study area

Tectonics and Stratigraphic Setting

The emergence of the Niger Delta Basin is linked to the evolution of the Benue Rift as an aulacogen, a failed arm of a triple junction, which occurred during the breakup of Gondwana supercontinent and the opening of the southern Atlantic Ocean during the Jurassic period (Maron, 1969; Burke *et al.*, 1972; Nwachukwu, 1972; Olade, 1975; Wright, 1981; Benkhlil, 1982). The Benue Trough is a northeast-southwest oriented folding rift basin that traverses Nigeria (Chukwu- Ike, 1981; Ajakaiye *et al.*, 1986). The stratigraphy of the southern Nigeria sedimentary basins occurred within the framework of three tectonic sedimentary cycles (Hoque and Nwajide, 1984). The initial cycle, which span from the Aptian to Coniacian epochs resulted in the accumulation of syn-rift sediments in various habitats, including continental and shallow marine settings. The second cycle followed the Santonian folding and uplift of the sediments from the first cycle. Subsequently, both the Anambra Basin and the Afikpo sub-basin had a period of subsidence. The initiation of the third cycle occurred during the deposition of Campanian to early Paleocene facies within the Anambra Basin and Afikpo sub-basin, followed by the subsequent lateral migration of sediment into the basin's interior (progradation) throughout the late Paleocene to present-day, resulting in the formation of the contemporary Niger Delta Basin. Fig. 2 is the stratigraphic succession in the Benue Trough, Anambra and the Niger Delta basins.

The Imo Formation is the basal lithostratigraphic unit of the outcropping part of the Niger Delta Basin. This is conformably overlain by the Ameki Group (Ameki, Nanka and Nsugbe formations). The Ameki Group is successively followed upwards by Ogwashi- Asaba and Benin formations (Nwajide, 2022).

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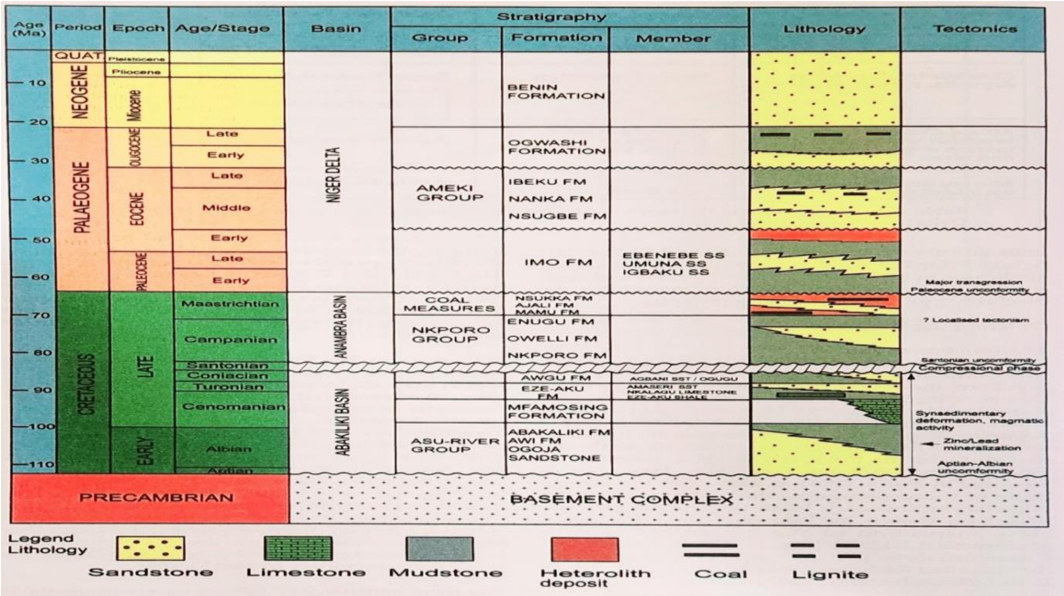

Fig. 2: Stratigraphic succession in the Benue Trough, Anambra and Niger Delta basins (Ekwenye and Nichol, 2015).

METHODOLOGY

Sediment samples were systematically collected from outcrop sections of the Nanka Formation within the study area. The samples were dried, pulverized and subjected to major elements analysis using X-ray Fluorescence (XRF), while trace elements were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Geochemical indices such as the Chemical Index of Alteration (CIA), Plagioclase index of Alteration (PIA)and Chemical Index of Alteration (CIA) were calculated using standards. The Index of Compositional Variability (ICV) was also determined to assess weathering and sediment maturity. Standard geochemical discrimination diagrams were used to classify the sandstones, interpret paleo- climatic condition of the source area, sediment provenance and tectonic setting and the paleoenvironment of deposition.

RESULT AND DISCUSSION

Major and Trace Elements Concentration

The results of geochemical analysis of the sediment samples from the investigated formation revealed the concentration of both major and trace elements in the sands (Table 1a & b).

The major element oxides are dominated by SiO_2, with concentration value ranges of 72.95 and 82.14 wt%. Al_2O_3 concentration varies from 3.50 to 8.32 wt%. The concentration values of between 1.74 and 4.34 wt%, 1.60 and 4.92 wt%, 0.05 and 0.56 wt%, 0.39 and 1.56 wt% and 0.14 and 0.82 wt% were obtained for Fe_2O_3, CaO, MgO, K_2O and Na_2O respectively (Table 1a). Comparison of the concentration values of the major element oxide in the sands of the Nanka Formation with the upper continental crust (UCC) of Rudnick and Gao (2003) and Post- Archean Australian Shale (PAAS) of Taylor and McLennan (1985) indicate enrichment of silica (SiO_2) and depletion of Al_2O_3, Fe_2O_3, CaO, MgO, K_2O and Na_2O. Trace elements such as Ni, Co, Zn and Zr are depleted whereas there is minor enrichment of U and Ba. Th is enriched with respect to UCC and depleted with respect to PAAS (Table 1b).

Table 1a: The result of the Major element oxides (wt.%), their Ratios, Indices and Discriminant Functions

	SAMPLE NO								
	D1	D2	E1	E2	R1	N2	Average	UCC	PAAS
SiO_2	74.83	72.95	79.5	80.02	82.14	80.97	78.402	66.00	62.80

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Al_2O_3	6.96	8.32	5.60	5.42	3.50	4.31	5.685	15.4	18.9
CaO	3.98	3.85	4.92	4.54	1.60	2.02	3.485	3.59	1.3
Fe_2O_3	3.80	4.34	1.74	2.02	2.59	3.56	3.008	5.04	7.22
MgO	0.56	0.48	0.28	0.22	0.09	0.05	0.280	2.48	2.20
K2O	1.00	1.56	0.90	1.04	0.39	0.46	0.975	2.80	3.70
Na_2O	0.82	0.63	0.51	0.27	0.17	0.14	0.423	3.27	1.20
Pb_2O_5	0.03	0.03	0.02	0.02	0.05	0.03	0.03	0.15	0.16
MnO	0.01	0.01	0.02	0.01	0.01	0.01	0.012	0.10	0.11
SO_3	0.06	0.05	0.03	0.02	0.01	0.01	0.030		
TiO_2	0.46	0.52	0.50	0.38	0.19	0.22	0.378	0.64	1.00
Cr_2O_5	0.01	0.01	0.01	0.01	0.01	0.01		0.64	1
LOI	6.96	7.22	5.96	6.02	9.24	8.15	7.258	-	-
Log (Fe_2O_3/K_2O)	0.404	0.444	0.286	0.288	0.822	0.889	0.522		
SiO_2/Al_2O_3	10.751	8.768	14.196	14.764	23.469	18.787	15.123	4.29	3.32
Log (SiO_2/Al_2O_3)	1.031	0.943	1.152	1.169	1.370	1.274	1.17		
Log (K_2O/Na_2O)	0.262	0.394	0.247	0.586	0.361	0.517			
CIA	52.489	57.939	46.940	48.092	61.837	63.193	54.915	52.76	70.39
PIA	67.836	74.021	55.281	58.977	71.721	71.714	66.592	53.49	79.05
CIW	59.184	65.00	50.771	52.981	66.414	66.615	60.161	58.88	82.72
MIA	4.978	15.878	-6.12	-3.816	23.674	24.386			
ICV	1.598	1.368	1.579	1.563	1.437	1.497	1.507	1.16	0.89
F1x	39.147	38.744	40.554	40.627	39.306	39.62	39.666		
F2x	42.66	14.34	23.83	22.97	22.34	18.49	24.11		
F1y									
F2y									
Al2O3/TiO2	15.13	16.00	11.20	14.26	18.42	19.59			

CIA = Chemical Index of Alteration

PIA = Plagioclase Index of Alteration

CIW = Chemical Index of Weathering

ICV = Chemical Index of Weathering

UCC = Upper Continental Crust

PAAS = Post-Archean Austrian Average

Table 1b: Trace Elements (ppm) and their ratios

	D1	D2	E1	E2	R1	N2	Average	UCC	PAAS
Cr								92.00	110.00
Ni	31.64	38.34	29.16	29.98	31.54	28.86	31.587	47.00	55.00
Zn	0.04	0.09	0.07	0.05	0.04	0.05	0.057	67.00	85.00
Co	8.81	8.94	6.33	6.14	5.82	5.13	6.862	17.30	23.00
Sb	10.34	9.32	7.01	8.21	7.93	8.30	8.518		
Zr	0.06	0.04	0.06	0.09	0.03	0.03	0.052	193.00	210.00
Mo	0.21	0.27	0.30	0.36	0.33	0.37	0.307		
Nb	15.63	10.93	7.93	9.00	11.19	12.04	11.120	12.00	19.00
Pb	20.32	18.04	21.32	20.43	23.68	20.98	20.795		
Cu	6.74	6.82	6.45	6.62	6.25	6.02	6.483	28.00	50.00
Th	13.98	13.72	10.15	12.18	11.92	12.14	12.353	10.50	14.60
U	8.91	8.54	6.81	6.27	8.31	8.72	7.927	2.70	3.10
Ba	683.04	732.51	428.62	372.63	923.11	950.15	681.677	628.00	650.00
Sc	227.13	221.88	219.36	227.05	241.63	238.74	229.298	14.00	16.00
Sr	47.32	53.62	58.54	61.23	63.78	62.97	57.910	320.00	200.00
Cd	2.13	2.85	2.45	3.12	3.00	3.17	2.787		
Rb	205.82	228.39	197.25	210.06	472.28	438.61	292.068	82.00	160.00
Hf	2.21	2.39	3.27	2.85	1.22	1.09	2.172	5.30	5.00
V	68.3	70.21	56.73	54.82	61.24	58.47	61.628		
Y	7.45	7.94	7.02	7.00	8.73	8.49	7.772		
La	0.05	0.05	0.08	0.11	0.05	0.03	0.062		
Sr/Ba	0.07	0.07	0.14	0.16	0.07	0.07			
Ni/Co	3.59	4.29	4.61	4.88	5.42	5.63			
V/Cr	1.00	1.03	0.83	0.80	0.90	0.85			
Cr/V	1.00	0.97	1.21	1.23	1.11	1.17			

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U/Th	0.64	0.62	0.67	0.51	0.70	0.72			
Y/Ni	0.24	0.21	0.24	0.23	0.28	0.29			

Correlation of Alumina with Major Element Oxides

Pearson correlation coefficient from bivariate plots of Al_2O_3 versus other major oxides, indicates that Al_2O_3 shows very strong positive correlations with MgO, K_2O and TiO_2 and strong positive correlation with Fe_2O_3 and CaO and very strong negative correlation with SiO_2. The strong positive correlation which exists between Al_2O_3 and other major element oxides suggest association in an aluminum silicate rocks such k-feldspars and ferromagnesian minerals. The depletion of these major element oxides and an enrichment of silica in the sands depict chemical weathering of the feldspars and the ferromagnesian minerals during which quartz are left behind because of its superior hardness and susceptibility to chemical weathering.

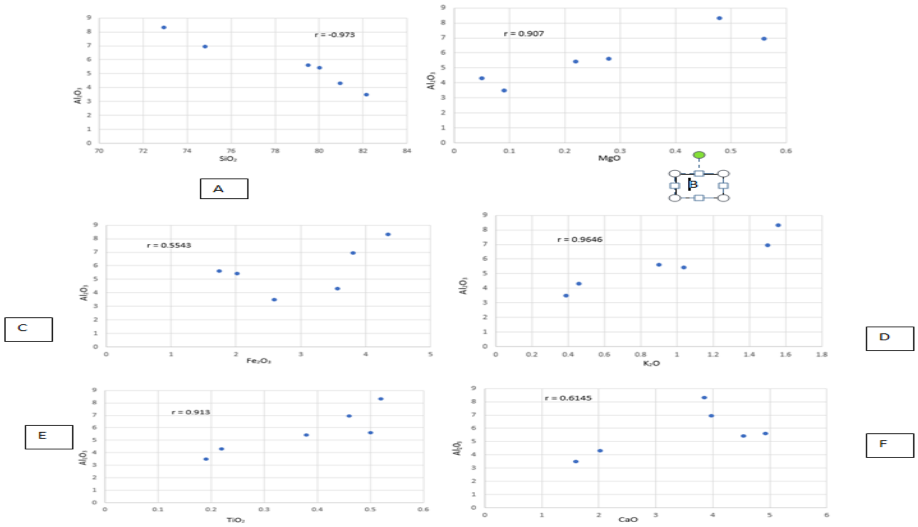

Fig. 3(a – f) Pearson correlation coefficient of major oxides

Classification of Nanka Sands

In the classification of the sand, Log (Fe_2O_3/K_2O) vs Log (SiO_2/Al_2O_3) of Herron (1988) employed indicated the sands to comprise of litharenites and sublitharenites. Litharenites contains a significant amount of rock fragments, typically exceeding 25% of the total composition while the sublitharenites is characterized by a moderate amount of rock fragments in its composition, typically ranging between 5% to 25%. The low Al_2O_3 contents of the sands placed them under arenite family.

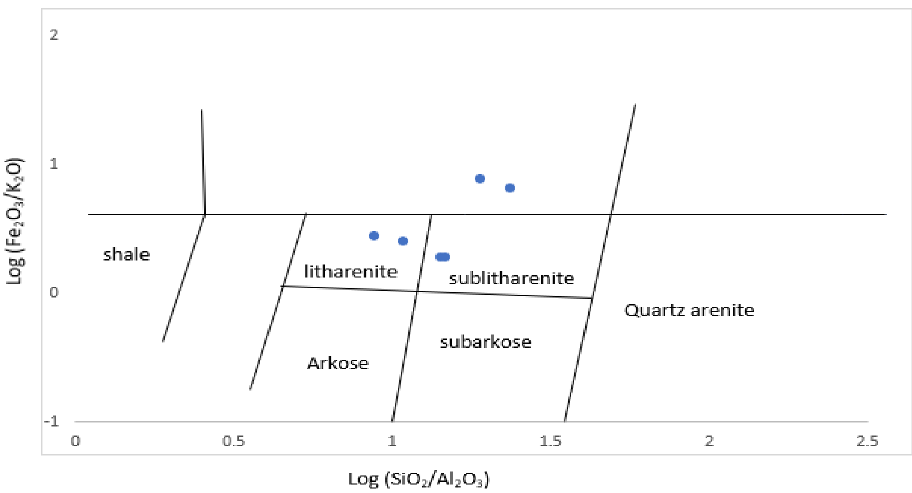

Fig. 4: The classification of Nanka Sands

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Paleo-Weathering History

The paleo- weathering history of the source area is assessed using the weathering Indices and the A- CN- K tenery plot.

Weathering Indices

The results of source area weathering evaluation using the weathering Indices (CIA, CIW, PIA and MIA) is presented in Table 1a and interpreted as Follows;

The Chemical Index of Alteration (CIA)

The calculated values of CIA range from 46.94 to 63.19%, with an average of 54.91% (Table 1a). This indicates moderate weathering of the source rocks.

The Chemical Index of Weathering (CIW)

The calculated CIW values varied from 50.77 to 66.41% (Table 1a), suggesting moderate weathering of the source rocks.

Plagioclase Index of Alternation (PIA)

The PIA value ranges of between 55.28 and 74.021% obtained is consistent with CIA and CIW, indicating moderate weathering.

Mineralogical Index of Alternation (MIA)

The MIA value ranges from indicate weak to incipient degree of weathering. The evidences from the weathering Indices suggest that chemical alteration of the rock was moderate.

Weathering Trend

The weathering trend for the source area of the Nanka sediments, the ($CaO + Na_2O$) – Al_2O_3 – K_2O triangular plot shows that almost all the sands of the area plot on a line parallel to the A-K line and thus, suggest weak to intermediate silicate weathering.

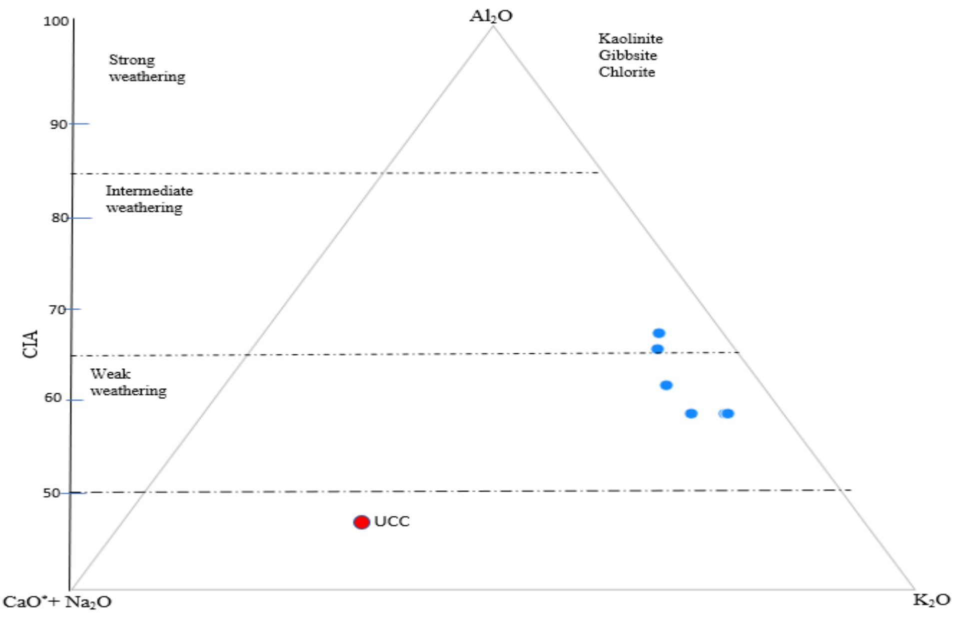

Fig. 5: Paleo-weathering trend of Nanka Sands using the A-CN-K triangular plot, developed by Nesbitt and Young (1984) and utilized by Fedo *et al*. (1995).

Index of Compositional Variability (ICV) and Sediment Maturity

The ICV values for the studied sandstone samples range from 1.368 to 1.598. Such values in sandstone indicate low compositional maturity. This is suggesting immature source rock that is rich in silicate minerals. The bivariate plot of ICV vs CIA for the Nanka Sand is presented as Fig. 6.

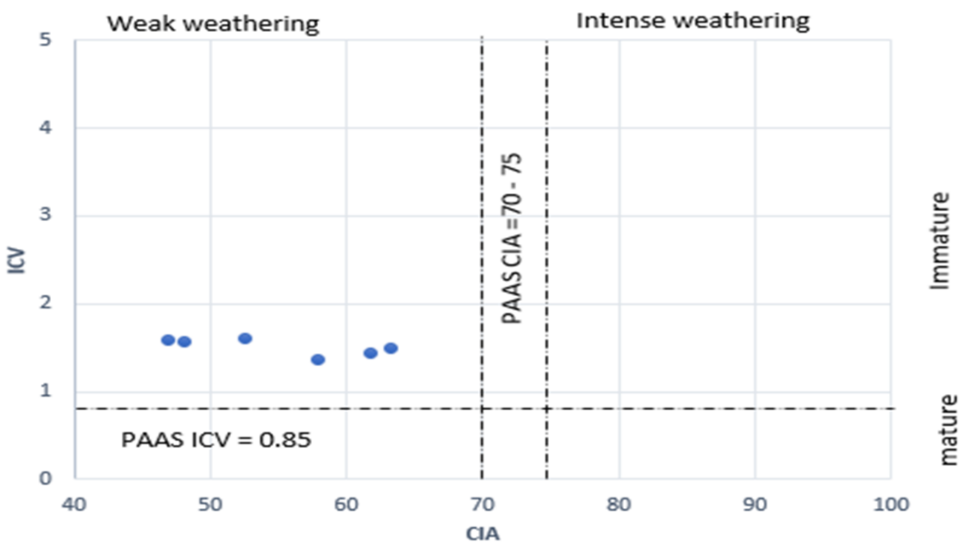

Fig. 6: ICV vs CIA plot showing the maturity and intensity of chemical weathering for the studied samples

Paleo- climatic Condition

The paleo- climatic condition of the source area for the Nanka Sand evaluated based on the bivariate plot of Suttner and Dutta (1986) indicated semi humid to humid climate (Fig. 7). The semi humid to humid climatic condition of the source area may have promoted rapid decomposition of feldspars and other ferromagnesian minerals in the source rocks and deposition of the sands and clays which is the typical attribute of the Nanka formation.

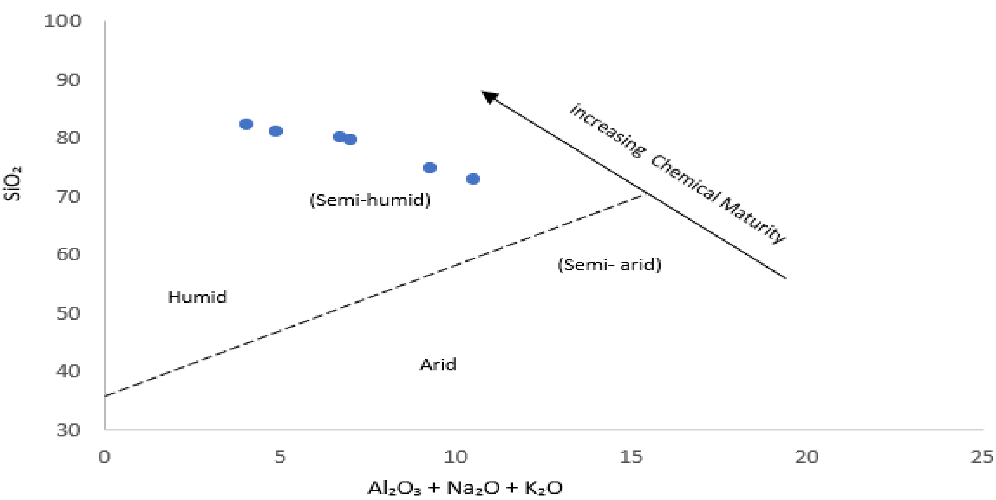

Fig. 7: bivariate plot Awka based on Suttner and Dutta (1986)

Provenance and Tectonic setting

Provenance

The Al_2O_3/TiO_2 ratio in sediments is a vital tool that helps to identify whether the sediments came from felsic, intermediate, or mafic igneous rocks (Garcia *et al.,* 1994; Hayashi *et al.,* 1997). According to Hayashi *et al.*

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(1997); High ratios (21–70) suggest the sediment came from felsic rocks (like granite), medium ratios (8–21) indicate an intermediate rock source (like andesite or diorite) and low ratios (3–8) mean the sediment was likely from mafic rocks (like basalt or gabbro). The Al_2O_3/TiO_2 ratios of the samples in Table 1 range from 11.20 to 19.59, which means they likely came from intermediate igneous rocks like andesite or diorite, rather than felsic (granite) or mafic (basalt) sources.

Fig. 8 (a) is a bivariate scatter diagram of Al_2O_3 /TiO_2 vs. SiO_2 of the investigated sediment (Le Bas *et al.*, 1986; Zaid and Al Gahtani, 2015) and Fig. 8(b) is the bivariate scatter plot of TiO_2 vs Ni (after Floyd *et al.*, 1989). The two plots suggested that the sediments of the Nanka Formation are mainly sourced from intermediate igneous rocks.

Fig. 9 is a Discriminant Function Analysis (DFA) plot used to classify sedimentary rocks based on their geochemical compositions, following the Roser & Korsch (1988) provenance classification system. The distribution of the samples across the DFA diagram provides insights into the tectonic setting and sedimentary processes affecting the study area. The presence of samples in the Quartzose Sedimentary Provenance field indicates that a significant portion of the sedimentary material has been subject to long-term weathering and recycling, typical of stable continental environments. Meanwhile, the presence of samples in the Intermediate Igneous Provenance field suggests the influence of volcanic arc activity, pointing to a mixed sedimentary input from both continental and volcanic sources. Overall, the data suggests a heterogeneous provenance.

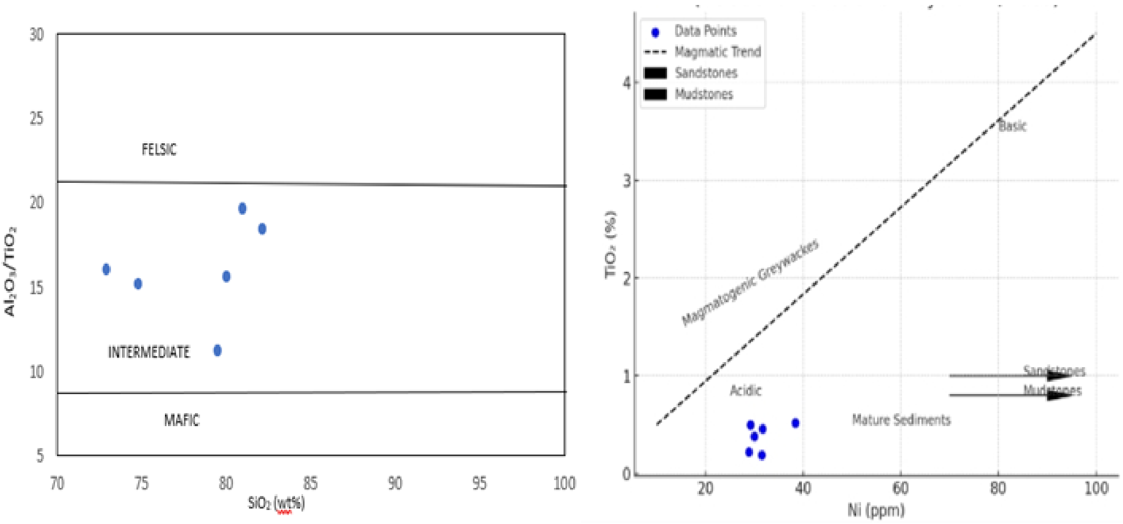

Fig. 8(a) Scatter diagram of Al_2O_3 /TiO_2 vs. (SiO_2) adj. of the investigated shales (Le *Bas et al.*, 1986; Zaid and Al Gahtani, 2015). Fig. 8(b) TiO_2 vs. Ni plot. Fields and trends after Floyd *et al.* (1989).

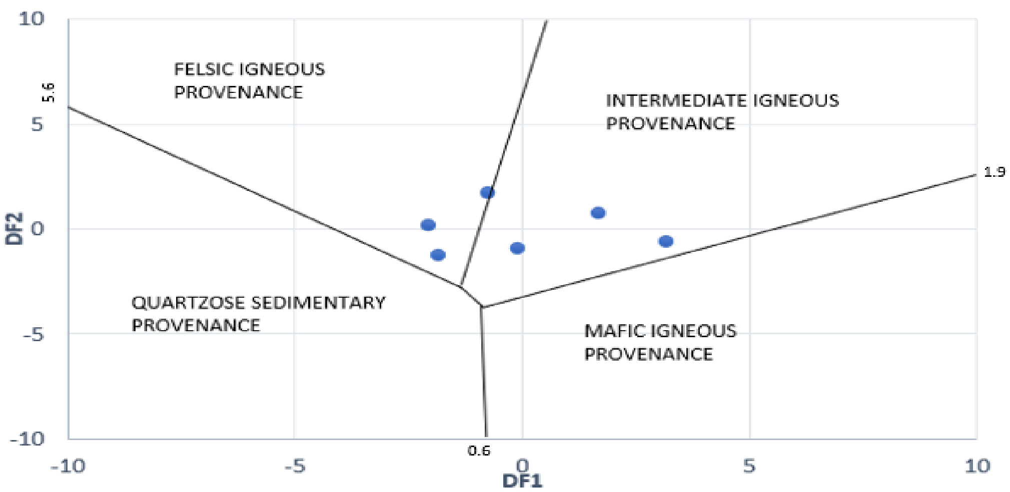

Fig. 9: Discriminant Function Analysis (DFA) plot following the Roser & Korsch (1988) provenance classification system

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Tectonic Setting

The bivariate plot of Roser and Korsch (1986) employed in the discrimination of the tectonic setting of the investigated sands plot in the field of passive margin (Fig. 10). Based on the geochemical plot, the data points fall within the region labeled "Passive Margin". This suggests that the sedimentary rocks of the Eocene sediments of Awka and its environs are likely derived from a passive margin tectonic setting.

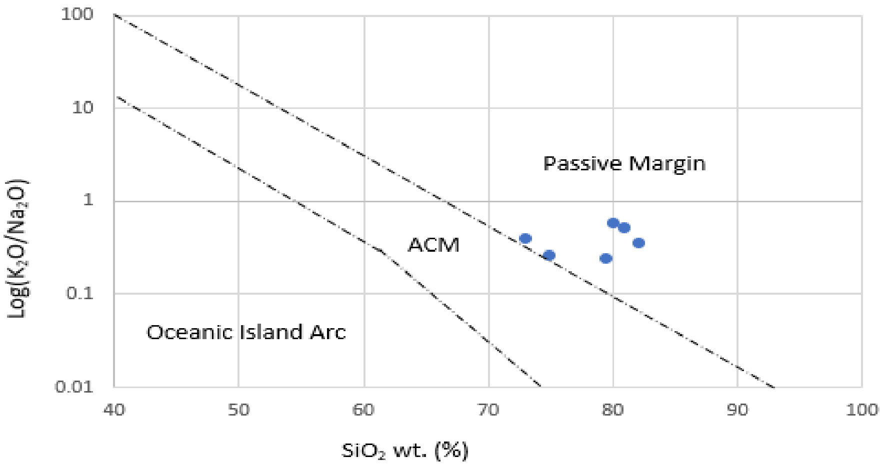

Fig. 10 sandstone-mudstone discrimination using the geochemical plot of log K_2O/Na_2O vs. SiO_2(%)

Depositional Environment

The Sr/ Ba ratio value ranges of 0.07 and 0.16 suggests freshwater environment and the bivariate plot of V vs Al2O3 after Mortazavi *et al.* (2014) indicated shallow marine plus fluvial input (Fig. 10). The oxidizing nature of the environment assessed using the V/ (V + Ni) vs. Ni/Co ratio (Hatch and Leventhal, 1992) and the bivariate plot of V/Cr vs Ni/Co after Jones and Manning (1994) (Fig. 11) indicated oxic to dysoxic depositional settings.

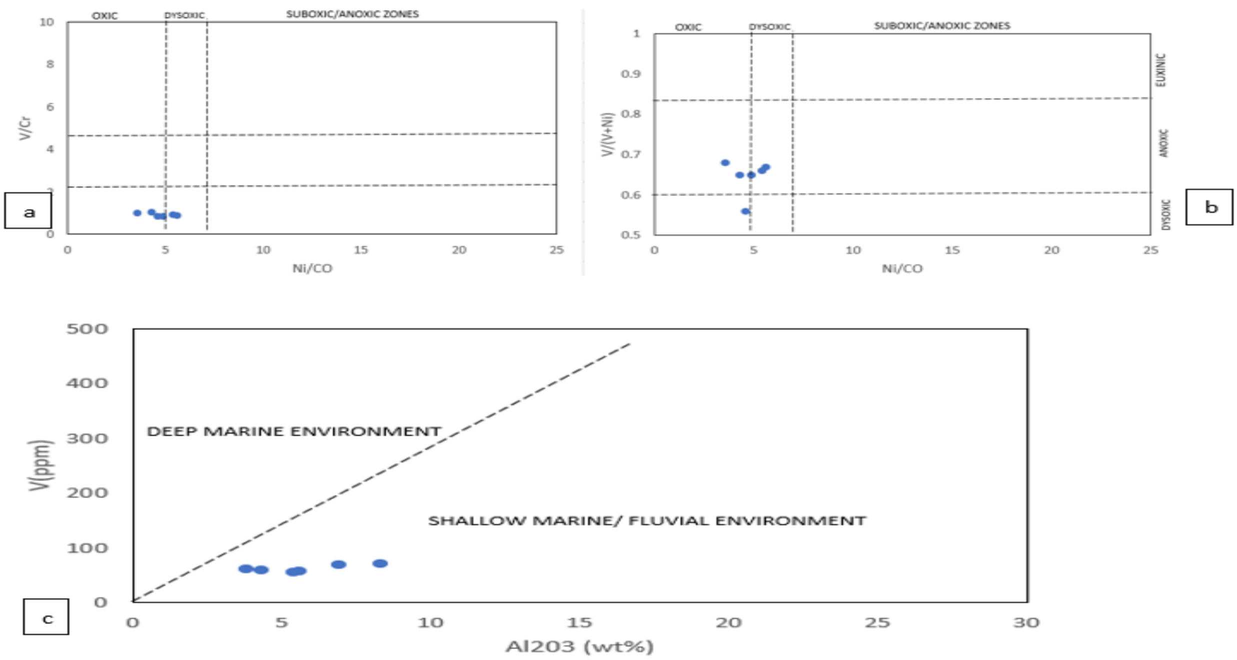

Fig 11(a) Cross plots of redox-sensitive trace metal ratios V/Cr vs. Ni/Co (Jones and Manning, 1994), and 11(b) Cross plots of redox-sensitive elements ratios V/(V + Ni) vs. Ni/Co (Hatch and Leventhal, 1992). 11(c) Paleo-environmental reconstruction of the investigated shales using V. vs. Al_2O_3 bivariate plot (After Mortazavi *et al.*, 2014).

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CONCLUSION

This study demonstrates that the Nanka Formation sediments were derived from moderately weathered intermediate igneous rocks and deposited in a passive margin setting. The geochemical signatures reflect a semi-humid to humid paleoclimate and a depositional environment transitioning from freshwater to shallow marine under oxic to dysoxic conditions. These results enhance our understanding of the sedimentary processes, provenance, and tectonic evolution within the southeastern margin of the Niger Delta Basin.

REFERENCES

1. Ahmad, M., Bhat, G. M., & Rashid, H. (2014). Geochemistry of sandstones from the Neoproterozoic Bhim Group, NW Indian Himalaya: Implications for provenance, weathering, and tectonic setting. Arabian Journal of Geosciences, 7(11), 4591–4606.
2. Ajakaiye, D. E., Hall, D. H., Millar, T. W., Verheijen, P. J. T., Awad, M. B., & Ojo, S. B. (1986). Aeromagnetic anomalies and tectonic trends in and around the Benue Trough, Nigeria. Nature, 319(6055), 582–584.
3. Basu, A. (1985). Weathering and its impact on sedimentary provenance studies. Journal of Sedimentary Petrology, 55(2), 231–234.
4. Benkhlil, J. (1982). Structural framework of the Benue Trough. Journal of African Earth Sciences, 1(3–4), 271–282.
5. Burke, K., Dessauvagie, T. F. J., & Whiteman, A. J. (1972). Geological history of the Benue Valley and adjacent areas. In T.F.J. Dessauvagie & A.J. Whiteman (Eds.), African Geology (pp. 187–205). Ibadan University Press.
6. Chukwu-Ike, I. N. (1981). Structural interpretation of aeromagnetic data over the Benue Trough, Nigeria. Geological Survey of Nigeria Bulletin, 28, 27–38.
7. Dickinson, W. R. (1985). Interpreting provenance relations from detrital modes of sandstones. In: Zuffa, G. G. (Ed.), Provenance of Arenites, NATO ASI Series (Vol. 148, pp. 333–361). Springer.
8. Dickinson, W. R. (1988). Provenance and sediment dispersal in relation to paleotectonics and paleogeography. In Kokelaar, B.P., & Howells, M.F. (Eds.), Margins of the Ocean Basins (pp. 121–146). Geological Society Special Publication No. 28.
9. Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., ... & Ryberg, P. T. (1983). Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geological Society of America Bulletin, 94(2), 222–235.
10. Edegbai, B. O., Ejeh, I. E., & Mamah, L. I. (2019). Petrography and geochemistry of sandstones from the Ajali Formation, southeastern Nigeria: Implications for provenance, tectonic setting and weathering. Journal of African Earth Sciences, 154, 66–80.
11. Ejeh, I. E., Odigi, M. I., & Ezeh, H. N. (2015). Geochemical evidence for provenance and tectonic setting of the Campanian-Maastrichtian sandstones in the Anambra Basin, Nigeria. Journal of African Earth Sciences, 111, 292–304.
12. Floyd, P. A., Leveridge, B. E., & Cave, R. (1989). Proterozoic metasedimentary rocks of southwestern England: Geochemistry and tectonic setting. Journal of the Geological Society, 146(1), 121–132.
13. Garcia, D., Cocherie, A., Guerrot, C., Kouamelan, A. N., & Trokon, H. (1994). Geochemistry and geochronology of the Dimbokro greenstones and associated granitoids (Côte d'Ivoire, West Africa): Evidence for crustal evolution in the Birimian (Early Proterozoic). Precambrian Research, 65(1–4), 207–224.
14. Hatch, J.R., Leventhal, J.S., 1992. Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) Stark shale member of the Dennis Limestone, Wabaunsee County, Kansas, USA. Chem. Geol. 99, 65–82.
15. Hayashi, K. I., Fujisawa, H., Holland, H. D., & Ohmoto, H. (1997). Geochemistry of ~1.9 Ga sedimentary rocks from northeastern Labrador, Canada. Geochimica et Cosmochimica Acta, 61(19), 4115–4137.
16. Herron, M. M. (1988). Geochemical classification of terrigenous sands and shales from core or log data. Journal of Sedimentary Petrology, 58(5), 820–829.

17. Hoque, M., & Nwajide, C. S. (1984). Tectonic evolution of the southern part of the Benue Trough (Nigeria). Geologische Rundschau, 73(2), 583–590.
18. Jones, B., & Manning, D. A. C. (1994). Comparison of geochemical indices used for the interpretation of paleoredox conditions in ancient mudstones. Chemical Geology, 111(1–4), 111–129.
19. Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., Zanettin, B., 1986. A chemical classification of volcanic rocks based on the total alkali-silica diagram. J. Petrol. 27, 745–750.
20. Maron, M. (1969). Origin and evolution of the Benue Trough. Bulletin of the Nigerian Mining and Geosciences Society, 9, 45–55.
21. Mortazavi, M., Jalilian, A., Aghanabati, A., & Taheri, S. (2014). Geochemical and petrographical investigations of the Garau Formation shales (Cretaceous) in western Iran: Implications for provenance, paleoclimate, and depositional conditions. Arabian Journal of Geosciences, 7(7), 2727–2743.
22. Nesbitt, H. W., & Young, G. M. (1984). Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. Geochimica et Cosmochimica Acta, 48(7), 1523–1534.
23. Nwachukwu, S. O. (1972). The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geological Magazine, 109(5), 411–419.
24. Nwajide, C. S. (1979). Sedimentological analysis of the Cretaceous sediments in the Middle Benue Trough. Sedimentary Geology, 22(3–4), 211–231.
25. Nwajide, C. S. (1980). Stratigraphy and sedimentation of the Cretaceous–Tertiary sediments in the Anambra Basin of eastern Nigeria. PhD Dissertation, University of Nigeria, Nsukka.
26. Nwajide, C. S. (2022). Geology of Nigeria's Sedimentary Basins. Shell Petroleum Development Company of Nigeria.
27. Oghenekome M.E., Chartterjee T.K., Hammond N.Q. and Van BeverDonker J.N., 2016. Provenance study from Petrography of the Late Permian- Early Triassic Sandstones of the Balfour Formation Karoo Supergroup, South Africa. Journal of Africa Earth Sciences 114:125-132
28. Olade, M. A. (1975). Evolution of Nigeria's Benue Trough (Aulacogen): A Tectonic Model. Geological Magazine, 112(6), 575–583.
29. Overare, B., Oboh-Ikuenobe, F. E., & Ejeh, I. E. (2020). Geochemical provenance and tectonic setting of Late Cretaceous–Paleocene sandstones in the Anambra Basin, Nigeria. Journal of African Earth Sciences, 169, 103895.
30. Roser, B. P., & Korsch, R. J. (1986). Determination of tectonic setting of sandstone–mudstone suites using SiO_2 content and K_2O/Na_2O ratio. The Journal of Geology, 94(5), 635–650.
31. Roser, B. P., & Korsch, R. J. (1988). Provenance signatures of sandstone–mudstone suites determined using discriminant function analysis of major-element data. Chemical Geology, 67(1–2), 119–139.
32. Rudnick, R.L., Gao, S., 2003. The composition of the continental crust. In: Treatise on Geochemistry, vol. 3. Elsevier – Pergamon, Oxford–London, pp. 1–64.
33. Short, K.C. and A.J. Stäuble. 1967. "Outline of Geology of Niger Delta". American Association of Petroleum Geologists Bulletin. 51: 761-779.
34. Suttner, L. J., & Dutta, P. K. (1986). Alluvial sandstone composition and paleoclimate. I. Framework mineralogy. Journal of Sedimentary Research, 56(3), 329–345.
35. Taylor, S. R., & McLennan, S. M. (1985). The Continental Crust: Its Composition and Evolution. Blackwell.
36. Wright, J. B. (1981). Review of the origin and evolution of the Benue Trough in Nigeria. Earth Evolution Sciences, 1(2), 98–103.
37. Zaid, S.M., Al Gahtani, F., 2015. Provenance, diagenesis, tectonic setting, and geochemistry of hawkesbury sandstone (middle triassic), southern sydney basin, Australia. Turk. J. Earth Sci. 24, 72–98.