GEOCHEMISTRY OF THE UPPER CRETACEOUS SHALES FROM GOMBE FORMATION, GONGOLA BASIN, UPPER BENUE TROUGH, NIGERIA: IMPLICATIONS FOR PROVENANCE AND TECTONIC EVOLUTION

*[1]Abiodun B. Ogbesejana, [2]Sulaiman Auwal Sabo, [1]Ikechukwu Ogadimma Alisi, [3]Augustine C. Egwu and [4]Babatope Oluseun Odusina

[1]Department of Industrial Chemistry, Faculty of Physical Sciences, Federal University Dutsin-Ma, P.M.B. 5001, Katsina State, Nigeria.
[2]Department of Chemistry, Faculty of Physical Sciences, Federal University Dutsin-Ma, P.M.B. 5001, Katsina State, Nigeria.
[3]BGI Laboratory Limited, 278 Port-Harcourt/Aba Expressway, Port-Harcourt, Rivers State, Nigeria.
[4]Department of Chemical Sciences, College of Science and Information Technology, Tai Solarin University of Education, Ijagun, Ijebu Ode, Ogun State, Nigeria.

*Corresponding authors' email: abiodunogbesejana@gmail.com

ABSTRACT

The Gombe Formation, situated in the northeastern region of Nigeria, contains shales in addition to various sedimentary lithologies such as sandstones, mudstones, and coals. Nonetheless, the comprehensive geochemical analyses of the major oxides of these shales remain inadequately documented to date. The current study aimed to elucidate the geochemical significance of major oxides of the shales from the Gombe Formation in the Upper Benue Trough, Nigeria, using x-ray fluorescence spectrometry (XRF) within the context of provenance, tectonic settings, and paleosalinity. The average concentration of the major oxides ranged from 0.02 to 34.93 % in the shales. Among the twenty-four (24) major oxides detected, the shales exhibit elevated concentrations of SiO_2, with $Al_2O_3 > Fe_2O_3 > SO_3 > MgO > CaO > SrO > BaO > K_2O > TiO_2 > Sb_2O_3 > CeO_2 > MnO$, whereas the remaining oxides exhibited low concentrations. This observation implies that the shales were predominantly composed of quartz minerals and deposited in marine environments. The relatively high concentrations of Fe_2O_3 (with an average value of 3.36 %) and MgO (with an average value of 2.48 %) in the samples suggest that the source rocks were likely of a mafic to ultramafic nature. The values of Al_2O_3/TiO_2 and SiO_2/Al_2O_3 in the shales ranged from 1.75 to 11.02 and 6.95 to 38.44, respectively. These values indicated their derivation from a mixture of felsic igneous and mafic igneous rocks and mixed compositional maturity in proximity to the active continental margin. This study demonstrated that major oxides serve as a robust tool for assessing the provenance and tectonic characteristics of the shales from the Gombe Formation within the Gongola Basin, Nigeria.

Keywords: Major oxides, Provenance, Tectonic settings, Gombe formation, X-ray fluorescence spectrometry

INTRODUCTION

The geology and stratigraphy of the Benue Trough (BT) are widely reported in the literature (Fatoye and Gideon, 2013b; Obaje *et al*., 1999; Idowu and Ekweozor, 1993; Nwajide, 1990; Benkhelil, 1989; Petters, 1982; Olade, 1975). The Upper Benue Trough is known for its complex sedimentary sequences and rich mineral resources (Nwajide, 2013). It underwent a compressional phase at the end of Santonian and Maastrichtian which culminated in the folding and faulting of the sediments. It is categorized into the N-S trending Gongola Basin and the E-W trending Yola Basin (Fig. 1) (Abubakar, 2014). The Cretaceous sedimentary strata of the Gongola Basin predominantly consist of five distinct geological formations, identified as the Bima, Yolde, Pindiga, Gombe, and Kerri-Kerri Formations. Conversely, the Yola Basin comprises the Bima, Yolde, Dukul, Jessu, Sekuliye, Numanha, and Lamja Formations (Fig. 2).

The Gombe Formation constitutes the most recent lithostratigraphic unit of the Cretaceous period within the north-south trending Gongola sub-basin of the Northern Benue Trough (Popoff et al., 1986; Nwajide, 2013). This formation is distinguished by its unconformable relationship with the underlying Fika Shale and is subsequently overlain by the Palaeocene Keri-Keri Formation. The lithological constituents of the Gombe Formation are methodically categorized into three discrete units (Zaborski et al., 1997): the basal interbedded unit, the middle bedded facies, and the upper red sandstone facies. The basal unit comprises alternating thin layers of silty shales, which contain plant detritus and fine to medium-grained sandstones, interspersed with flaggy ironstones. The central section is distinguished by uniformly horizontally stratified fine to medium-grained quartz arenite, interspersed with silts, silty clays, and ironstones; in contrast, the upper portion of the formation is chiefly comprised of brick-red sandstone. The grain sizes within the formation display a spectrum ranging from pebble dimensions to medium-grained sandstones, exemplifying trough, tabular, and planar cross-bedding configurations. The Gombe Formation is ascribed to a Maastrichtian age (Carter et al. 1963; Kogbe 1976; Popoff et al. 1986).

Shale is a sedimentary rock that's made up of mud, clay minerals, and tiny fragments of other minerals, like quartz and calcite. Shale is fine-grained and fissile. It's one of the most abundant sedimentary rock types and can be found at the Earth's surface and deep underground. The concentrations of Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, and iron oxides within sedimentary lithologies generally exceed 0.1%, thereby categorizing them as major elements. These major elements form an essential aspect of the inorganic mineralogy found in sedimentary rocks and act as pivotal factors affecting the industrial properties and processing methodologies of coal (Seredin and Dai, 2012; Finkelman et al., 2019; Dai et al., 2020). Notwithstanding the invaluable contributions of previous researchers who have explored the geochemical

characteristics of sedimentary rocks from the Gombe formation (Mohammed et al., 2018; Ayinla et al., 2017a, 2017b; Usman et al., 2017), a thorough investigation into the geochemistry of major oxides in the shales of this formation is notably lacking or inadequately documented. Consequently, there exists a pressing requirement for a detailed inquiry into the geochemical significance of major

oxides in the shales from Gombe formation. To achieve this aim, a total of twenty outcrop samples were collected through sedimentological methods and subsequently subjected to analysis using x-ray fluorescence spectrometry (XRF), which led to the identification and assessment of twenty-four distinct major oxides.
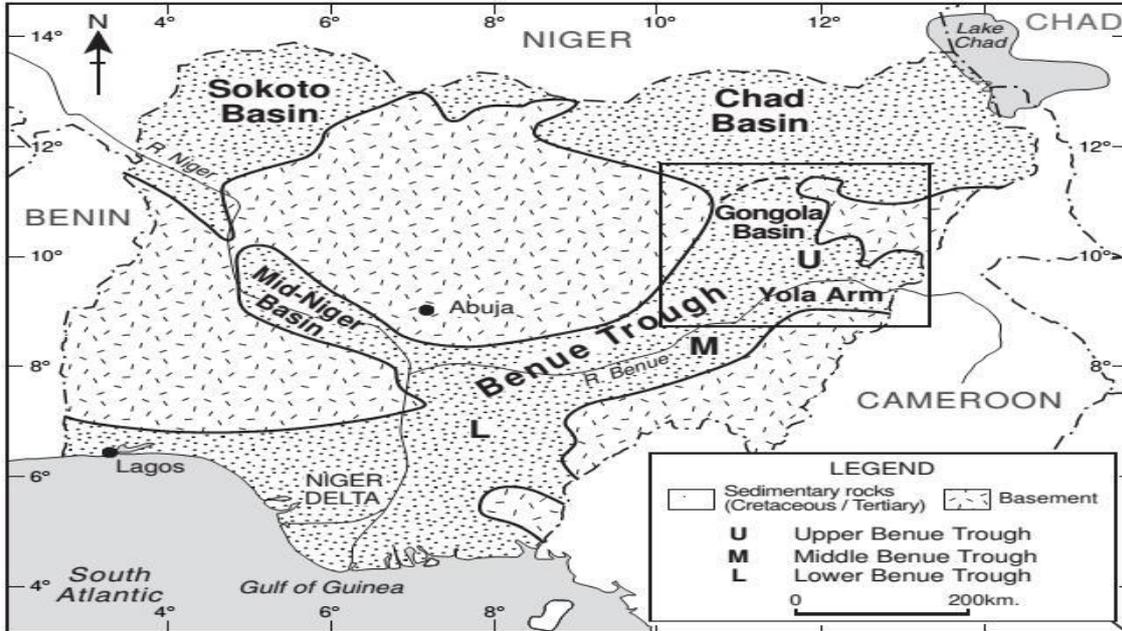
Figure 1: Generalised geological map of Nigeria showing the location of the Gongola Basin (Abubakar, 2014)

Figure 2: Stratigraphic successions of Upper Benue Trough (Obaje *et al.*, 2006)

MATERIALS AND METHODS
Sampling
The challenges encountered in the procurement of subsurface samples, considering the constraints imposed by governmental regulations, necessitated the utilization of outcrop samples for this study. A total of 20 outcrop samples were systematically collected from shaly sequences within the Gombe Formation in the Gongola Basin, which encompass a diverse array of sedimentary logs and facies. Acknowledging that weathering consistently represents a considerable challenge for inorganic geochemical analyses of outcrop sediments, weathered rock surfaces were methodically removed by excavating to an approximate depth of 0.5 m at each sampling site to secure samples that were both fresh and unweathered.

Sample preparation
All glassware utilized in the experimental methodology underwent rigorous washing and rinsing procedures employing distilled water. Subsequently, these items were immersed in a chromic acid solution for 24 hours. Following this, the glasswares were thoroughly rinsed with deionized distilled water and subsequently dried in an oven maintained at a temperature of 110˚C. Thereafter, they were placed in desiccators to facilitate the cooling process (Akinlua et al., 2008). The shale samples were processed through grinding using an agate mortar. The resultant pulverized samples were sifted individually through a sieve with a mesh size of 100μm. To avert cross-contamination, the pestle and mortar were meticulously cleaned following the grinding of each distinct sample.

X-ray fluorescence spectrometry (XRF) analysis
4g rock powders with a grain size of approximately 300 meshes underwent compression to form a pellet inside a disk measuring 32mm in diameter at a pressure of 32MPa. Subsequently, the pellets were analyzed at the analytical laboratory, Department of Chemistry, Umaru Musa University, Katsina State, Nigeria using an Axios 4.0 X-ray fluorescence spectrometer. The operational parameters for the XRF machine included V=60kV, I=120mA, and P=4kW. To ensure the accuracy of major oxide measurements, the average precision was maintained at below 2%. The results of major oxides are presented in Table 1.

RESULTS AND DISCUSSION
Distribution of Major Oxides
Table 1 shows the concentrations of the major oxides in the shales from the Gombe Formation. The shales were found to contain twenty-four (24) major oxides, including SiO_2, Al_2O_3, Fe_2O_3, TiO_2, MgO, K_2O, P_2O_5, SO_3, ZrO_2, SrO, MnO, CaO, and Cl (Table 1). The average concentrations of the major oxides range from 0.01 to 34.93% (Table 1, Fig. 3). With an average value of 34.93%, SiO_2 has the highest concentration. The majority of SiO_2 comes from the remains of extinct marine life that lived in the oceans when the mudstones were being deposited (Niu et al., 2015). This is subsequently followed by Al_2O_3, Fe_2O_3, SO_3, MgO, CaO, SrO, BaO, K_2O, TiO_2, Sb_2O_3, CeO_2, and MnO, which have the average values of 11.79 %, 3.96 %, 3.89 %, 2.36 %, 1.81 %, 1.49 %, 1.29 %, 1.04 %, 0.93 %, 0.81 %, 0.31 %, and 0.30 %, respectively (Table 1, Fig. 3), while the concentrations of the remaining oxides are low (Table 1, Fig. 3).

Table 1: Concentrations of the major oxides in the studied shales

Samples	Fe₂O₃ %	SiO₂ %	Al₂O₃ %	MgO %	P₂O₅ %	SO₃ %	TiO₂ %	MnO %	CaO %	K₂O %	CuO %	ZnO %	V₂O₅ %
SGS1	4.87	25.41	12.92	2.01	0.05	3.34	1.86	0.40	1.73	1.21	0.005	0.02	0.100
SGS2	5.04	26.99	15.41	2.05	0.09	2.44	1.37	0.34	1.08	1.14	0.005	0.03	0.090
SGS3	4.82	27.34	15.03	1.86	0.08	3.04	1.40	0.39	1.19	1.29	0.005	0.03	0.100
SGS4	4.36	26.93	13.76	2.31	0.03	5.18	1.11	0.23	1.25	1.16	0.005	0.02	0.060
SGS5	4.03	37.54	14.32	2.46	0.05	1.81	1.21	0.37	0.93	1.49	0.005	0.02	0.050
SGS6	3.74	33.27	10.92	2.36	0.05	2.96	0.83	0.38	1.77	1.62	0.003	0.03	0.030
SGS7	4.32	30.24	8.07	2.09	0.00	5.26	0.63	0.33	3.43	0.75	0.004	0.01	0.020
SGS8	3.96	33.64	10.67	1.89	0.04	6.62	0.43	0.24	2.30	0.53	0.005	0.02	0.020
SGS9	3.49	37.42	8.68	3.32	0.02	7.73	0.41	0.26	3.87	0.68	0.003	0.08	0.020
SGS10	0.93	66.36	6.02	3.13	0.00	0.72	0.16	0.10	0.79	0.59	0.001	0.01	0.004
SGS1A	4.94	36.07	11.92	2.36	0.05	2.66	0.93	0.38	1.47	1.32	0.003	0.02	0.030
SGS2A	3.99	31.34	9.07	2.09	0.00	5.26	0.6	0.37	3.43	0.73	0.004	0.02	0.020
SGS3A	3.94	35.64	10.77	1.89	0.04	6.62	0.63	0.26	2.30	0.74	0.002	0.05	0.030
SGS4A	3.79	37.52	9.62	3.32	0.02	7.73	0.51	0.26	3.87	0.68	0.003	0.08	0.020
SGS5A	0.83	67.68	6.15	3.35	0.00	0.73	0.16	0.10	0.79	0.59	0.001	0.01	0.004
SGS6A	3.87	26.41	13.92	2.01	0.05	3.24	1.36	0.30	1.53	1.21	0.005	0.02	0.100
SGS7A	5.04	26.99	15.41	2.05	0.09	2.44	1.37	0.34	1.08	1.14	0.005	0.03	0.090
SGS8A	4.82	27.34	15.03	1.86	0.08	3.04	1.40	0.39	1.19	1.29	0.005	0.03	0.100
SGS9A	4.36	26.93	13.76	2.31	0.03	5.18	1.11	0.23	1.25	1.16	0.005	0.02	0.060
SGS10A	4.03	37.54	14.32	2.46	0.05	1.81	1.21	0.37	0.93	1.49	0.005	0.02	0.050
Average	3.96	34.93	11.79	2.36	0.04	3.89	0.93	0.30	1.81	1.04	0.00	0.03	0.050

Samples	PbO %	Rb₂O %	Ga₂O₃ %	NiO %	Cl %	Ta₂O₅ %	SrO %	Nb₂O₅ %	Sb₂O₃ %	CeO₂ %	BaO %	LOI
SGS1	0.008	0.002	0.002	0.005	0.09	0.020	2.98	0.12	1.00	0.730	2.11	39.01
SGS2	0.006	0.001	0.002	0.007	0.09	0.020	2.62	0.12	1.00	0.570	1.76	37.73
SGS3	0.007	0.002	0.002	0.005	0.07	0.020	2.79	0.12	1.00	0.670	2.09	36.65
SGS4	0.007	0.002	0.002	0.006	0.12	0.020	1.99	0.12	0.51	0.450	1.30	39.07
SGS5	0.006	0.003	0.002	0.005	0.11	0.040	1.65	0.12	0.56	0.280	0.91	32.03
SGS6	0.006	0.002	0.002	0.004	0.10	0.010	1.27	0.14	1.00	0.240	0.72	38.54
SGS7	0.003	0.001	0.001	0.004	0.06	0.020	0.41	0.12	1.00	0.010	1.00	42.22
SGS8	0.001	0.001	0.002	0.006	0.06	0.020	0.44	0.11	0.54	0.040	1.00	37.42
SGS9	0.006	0.001	0.001	0.005	0.08	0.020	0.50	0.12	1.00	0.040	1.00	31.24
SGS10	0.003	0.001	0.001	0.002	0.06	0.006	0.32	0.11	0.53	0.030	1.00	19.12
SGS1A	0.006	0.002	0.002	0.004	0.10	0.010	1.17	0.12	1.00	0.230	0.72	34.48
SGS2A	0.004	0.002	0.001	0.005	0.08	0.020	0.51	0.12	1.00	0.009	1.00	40.33
SGS3A	0.001	0.002	0.002	0.006	0.07	0.020	0.48	0.11	0.54	0.040	1.00	34.82
SGS4A	0.006	0.001	0.001	0.005	0.08	0.020	0.50	0.12	1.00	0.040	1.00	29.80
SGS5A	0.003	0.001	0.001	0.002	0.06	0.006	0.32	0.11	0.53	0.030	1.00	17.54
SGS6A	0.008	0.002	0.002	0.005	0.09	0.020	2.78	0.12	1.00	0.730	2.11	39.11
SGS7A	0.006	0.002	0.002	0.007	0.09	0.020	2.62	0.12	1.00	0.570	1.76	37.73
SGS8A	0.007	0.002	0.002	0.005	0.07	0.020	2.79	0.12	1.00	0.670	2.09	36.65
SGS9A	0.007	0.002	0.002	0.005	0.12	0.020	1.99	0.12	0.51	0.450	1.30	39.07
SGS10A	0.006	0.003	0.002	0.005	0.11	0.020	1.65	0.12	0.56	0.280	0.91	32.05
Average	0.010	0.000	0.000	0.000	0.09	0.020	1.49	0.12	0.81	0.310	1.29	34.73
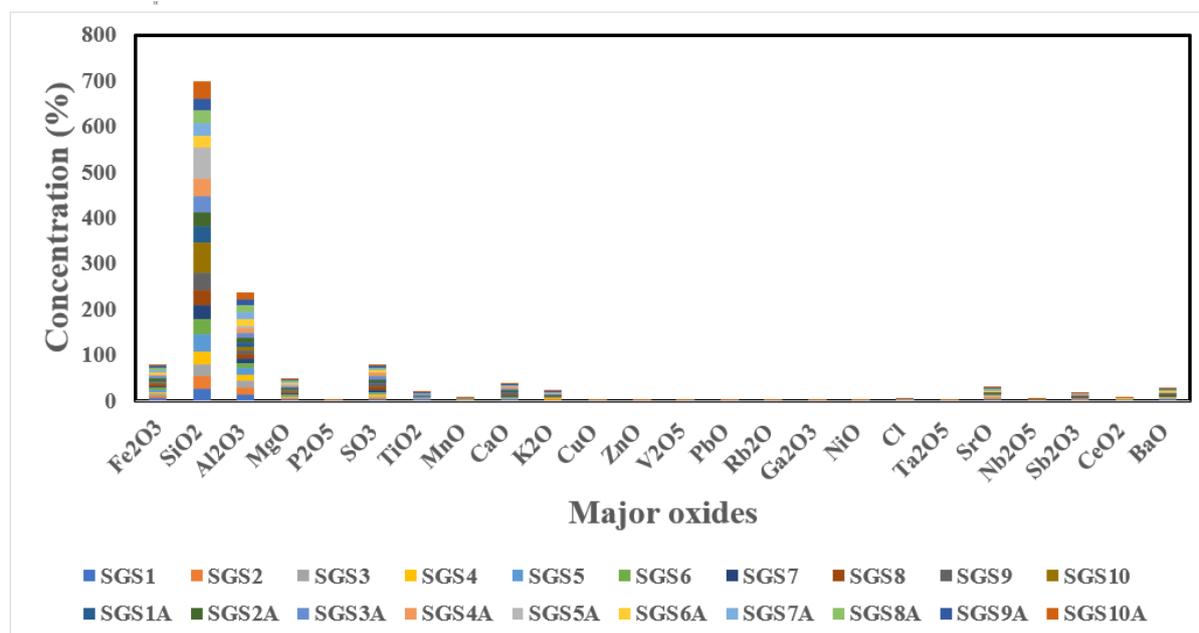
Figure 3: The histogram of the contents of the major oxides in the studied shales

According to Yang and Du (2017), the weathering processes of minerals rich in iron and aluminum that were present in the source area of the shale location are the sources of Al_2O_3 and Fe_2O_3. Furthermore, the presence of relatively high amounts of magnesium oxide (MgO; average value of 2.36%) and calcium oxide (CaO; average value of 1.81%) in the shales suggests weathering of calcium- and magnesium-rich minerals in the parent rock as well as contributions from marine environments (Niu et al., 2015). Previous research on Eocene to Recent sediments from Western Niger Delta,

Nigeria has shown this distribution trend (Edema et al., 2016). Additionally, Pundaree et al. (2015) noted that Fe_2O_3 and MgO are the primary characteristics of mafic rocks. Therefore, the relatively high contents of Fe_2O_3 (average of 3.96%) and MgO (average of 2.36%) in the examined samples indicate that the source rocks are probably mafic to ultramafic in composition. The Gombe shales may have been deposited in a reducing environment because they do not contain sodium oxide (Na_2O). Under reducing conditions, sodium cations may be extracted from the sediment via interactions

with organic matter or sulfide compounds. Moreover, when the sedimentary basin is located relatively far from the source of sodium-rich minerals, there may not be enough sodium available for the production of Na_2O. The high SiO_2 concentration found in the Gombe shale samples which ranged from 25.41% to 67.68% with an average of 34.93% (Table 1) indicates that the shales are primarily quartz-rich sedimentary rocks, like sandstone, which has a high quartz content and is therefore remarkably resistant to weathering (Nesbitt and Young, 1982). However, the presence of Fe_2O_3 (ranging from 0.83 to 5.04 % with an average value of 3.96%) and Al_2O_3 (ranging from 6.02 to 15.41 % with an average value of 11.79 %; Table 1) in both significant amounts indicates that the rock has undergone some weathering since these oxides are typically associated with the breakdown of feldspars and iron-rich minerals, respectively (Federman et al., 1999).

The Al_2O_3 plots against a few major oxides, as shown in Figures 4 and 5, exhibit strong positive correlations with Fe_2O_3, P_2O_5, K_2O, and TiO_2, while showing negative correlations with SiO_2, MgO, and CaO. These findings likely suggest that these major oxides are not exclusively hosted by clay minerals (Li et al., 2019). The other oxides, except SiO_2, MgO, and CaO, only weakly follow the trends of positive correlations (increasing as Al_2O_3 increases). This suggests that the presence of quartz is not affected by a unique paleoenvironment that promotes the growth of siliceous tests and skeletons (such as radiolarian or siliceous sponges) (Li et al., 2019). Additionally, in the plots of SiO_2 vs major elements (Figures 6 and 7), MgO exhibits a positive correlation, whilst other major oxides show a negative correlation, further indicating that they are linked to clay and/or micaceous minerals in the sediments (Ogbesejana et al., 2024b, 2024c; Pundaree et al., 2015). There is a very faint positive correlation between CaO and MgO, indicating that minerals other than carbonates make up these shales (Fig. 7d). The concentration of CaO and MgO in these shales may have been caused by carbonate minerals, given the decreased LOI, which is primarily ascribed to losses of CO_2 and organic matter (Table 1).

Provenance

The absence of Na_2O among the major oxides made the discrimination diagram suggested by Roser and Korsch (1986) for the division of sedimentary origins into four different provenance zones—mafic, intermediate, felsic, and igneous provenances, unsuitable for the present study. The main purpose of the Al_2O_3/TiO_2 ratios in rocks and sediments is to infer the compositional properties of the original rocks. Al_2O_3/TiO_2 ratios between 21 and 70, 8 to 21, and 3 to 8 were shown by Hayashi et al. (1997) to be associated with felsic igneous, intermediate, and mafic igneous rocks, respectively. In the present study, the values of Al_2O_3/TiO_2 range from 6.95 to 38.44 with an average value of 16.08 (Table 2), implying sediments originated from a mixture of felsic igneous to mafic igneous rock types. Ogbesejana et al. (2024a) have reported similar inferences on the Late Paleocene shales from Dange and Gamba formations, Sokoto Basin, Nigeria. Additionally, the compositional maturity of these sediments was evaluated using the SiO_2/Al_2O_3 ratio values. It is well known that this ratio consistently shows higher values when the sediment composition is mature. According to Roser et al. (1996), acidic igneous rocks usually have a ratio of about 5, whereas basic igneous rocks have a SiO_2/Al_2O_3 value of 3. Therefore, sedimentary maturity is indicated by values greater than 5 in clastic deposits. The SiO_2/Al_2O_3 values of the shales examined in this study range between 1.75 and 11.02, with an average value of 3.51 (Table 2), thereby suggesting a mixed compositional maturity (Table 2). The cross plots of TiO_2 and K_2O relative to Al_2O_3, illustrated in Figure 8, indicate that the shales are primarily comprised of granite, illite, and muscovite minerals (Ogbesejana et al., 2024b, 2024c; Hayashi *et al*., 1997).

Tectonic settings

Understanding the tectonic settings of a basin is crucial for paleogeography research as well as for the search for petroleum and other economically valuable resources. Numerous researchers have emphasized the value of using discrimination diagrams for the major element geochemical analysis of sedimentary rocks to infer tectonic settings (e.g., Roser and Korsch, 1986; Bhatia, 1983). However, the absence of Na_2O among the major oxides made it impossible to use these diagrams in the current study. Consequently, we adopted the diagrams of Fe_2O_3+MgO versus TiO_2 and Al_2O_3/SiO_2 (Bhatia, 1983) (Fig. 9). The tectonic settings are effectively divided into four distinct zones by these discrimination diagrams: oceanic island arc, continental island arc, active continental margin, and passive margin. The shales in the present investigation were grouped on the plots of Fe_2O_3+MgO vs TiO_2 (Fig. 9a) and Fe_2O_3+MgO versus Al_2O_3/SiO_2 (Fig. 9b) close to the active continental margin. Oni *et al.* (2014) have reported similar conclusions on the core samples from well-Y, onshore Niger Delta Basin, Nigeria.

(a) Plot of Al_2O_3 % versus SiO_2 %; $y = -0.1894x + 18.403$, $R^2 = 0.5378$

(b) Plot of Fe_2O_3 % versus Al_2O_3 %; $y = 0.2934x + 0.4995$, $R^2 = 0.6025$
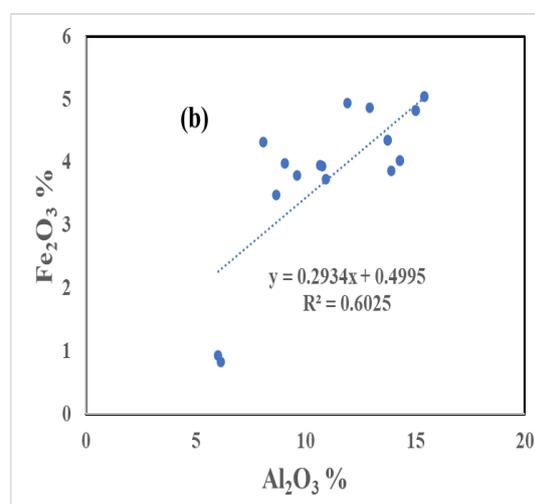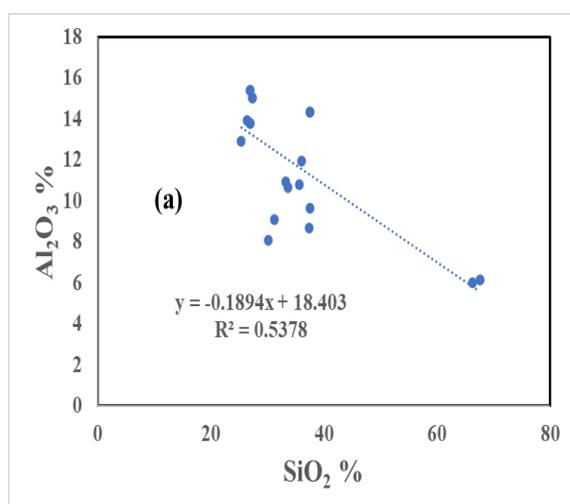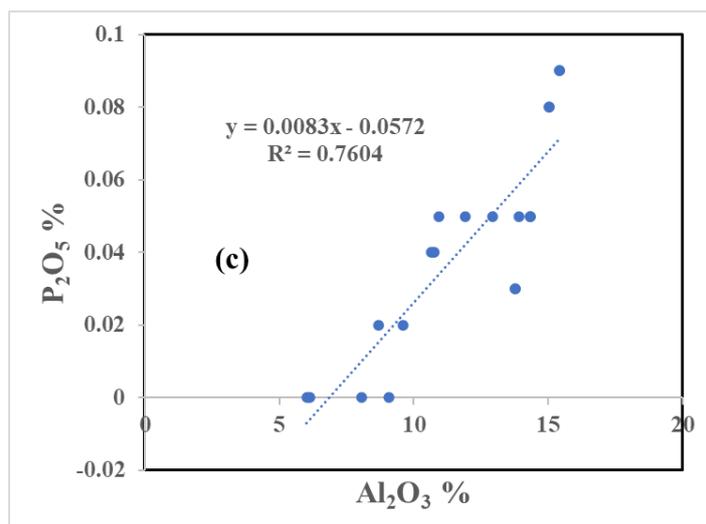
Figure 4: Correlation plots of Al$_2$O$_3$ vs (a) SiO$_2$, (b) Fe$_2$O$_3$, and (c) P$_2$O$_5$ in Gombe shales
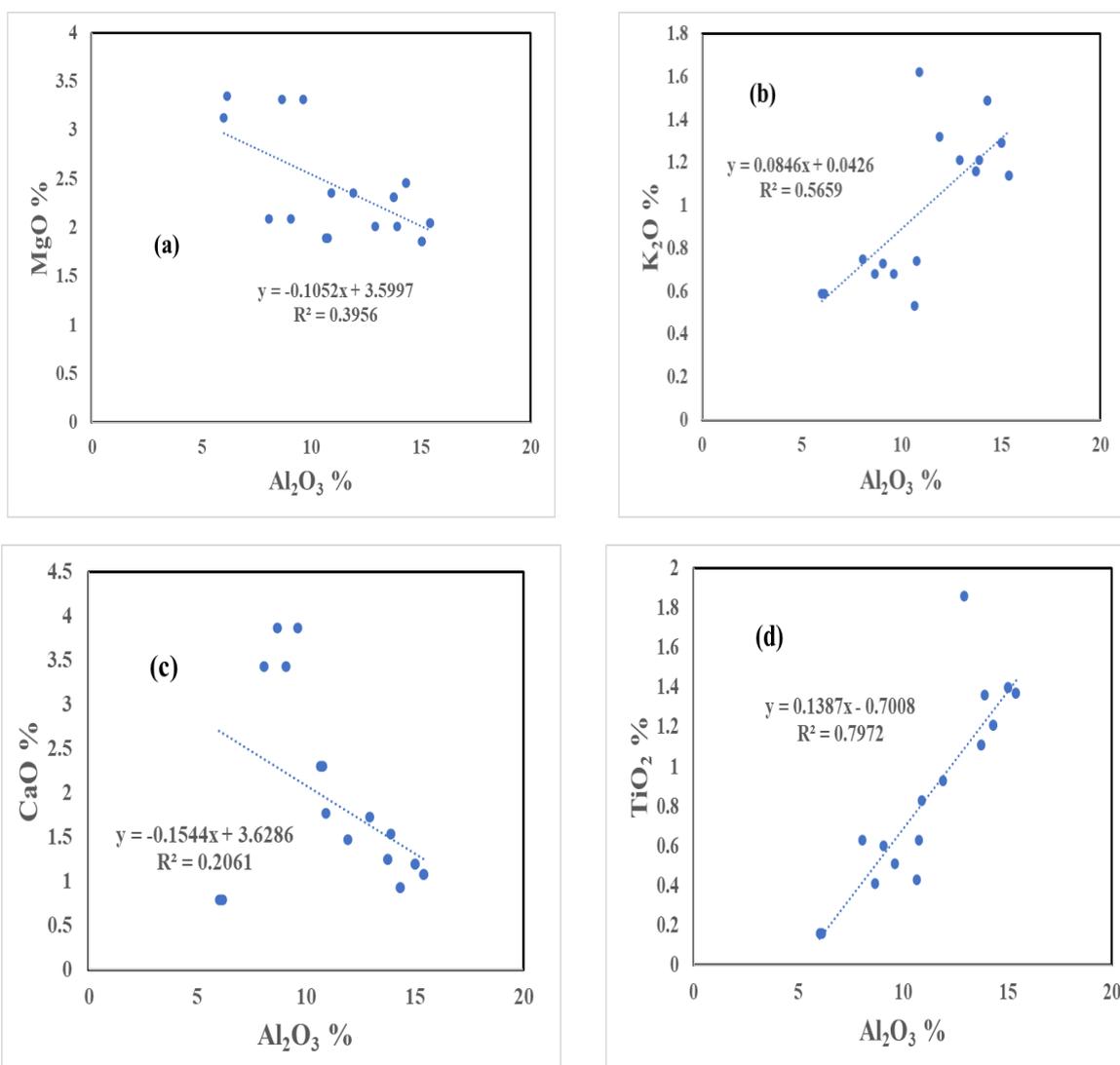
Figure 5: Correlation plots of Al$_2$O$_3$ vs (a) MgO, (b) K$_2$O, (c) CaO, and (d) TiO$_2$ in Gombe shales
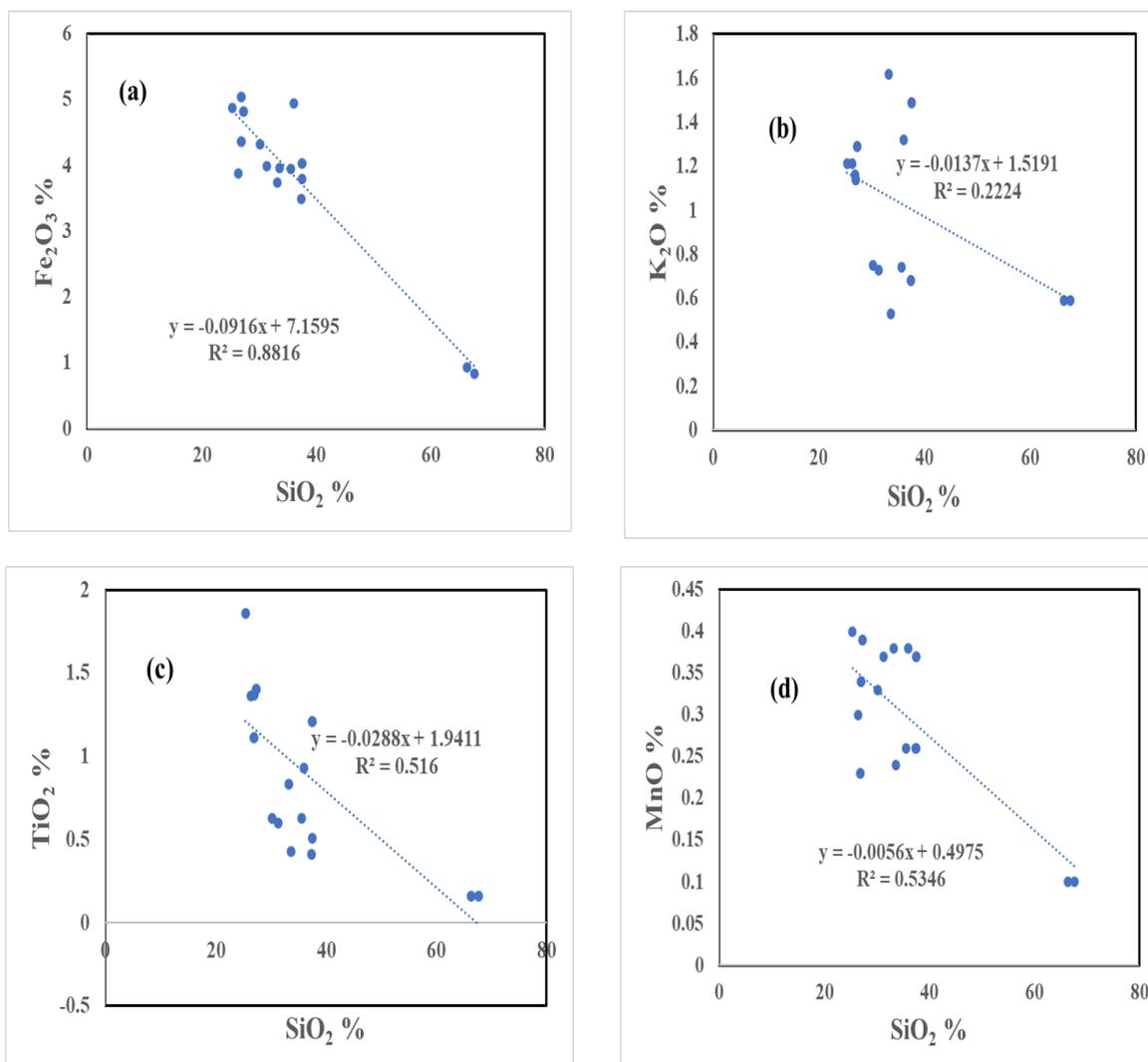
Figure 6: Correlation plots of SiO$_2$ vs (a) Fe$_2$O$_3$, (b) K$_2$O, (c) TiO$_2$, and (d) MnO in Gombe shales
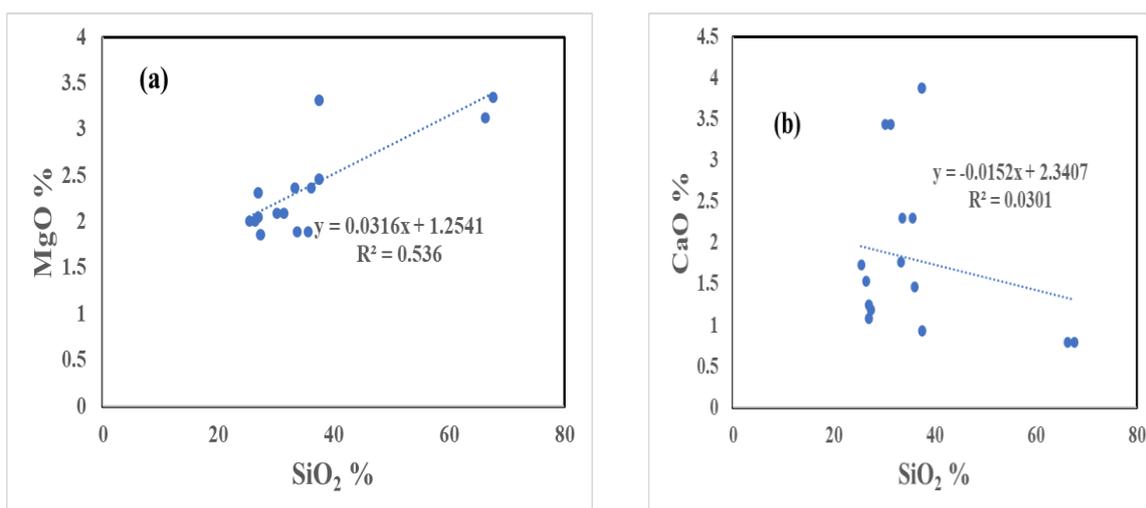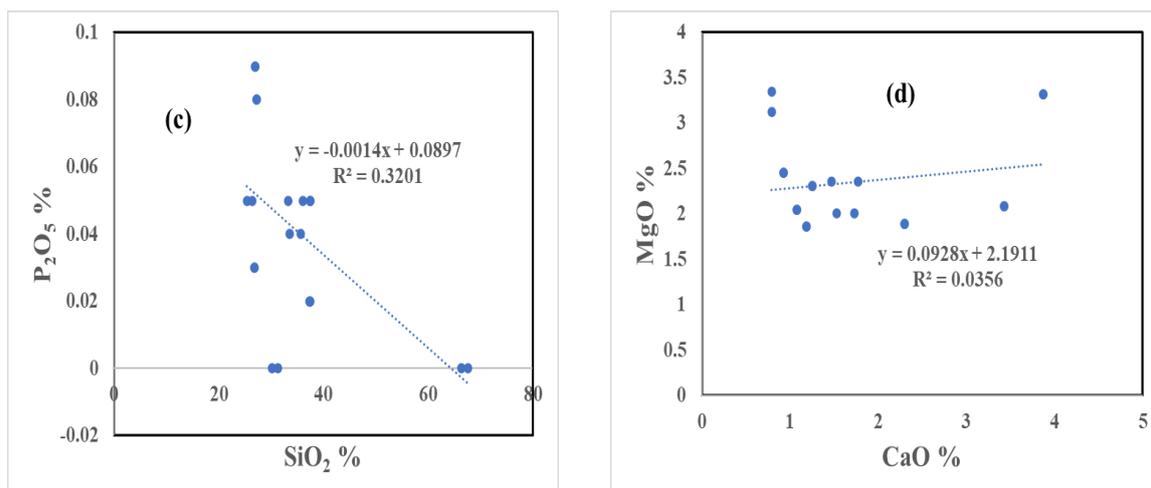
Figure 7: Correlation plots of SiO₂ vs (a) MgO, (b) CaO, (c) P2O5, and (d) Plot of MgO vs. CaO in Gombe Shales

Table 2: Geochemical ratios computed from the major oxides in the shales

Samples	Al_2O_3/TiO_2	MgO/Al_2O_3	K_2O/Al_2O_3	CaO/Al_2O_3	Fe_2O_3/Al_2O_3	SiO_2/Al_2O_3	SiO_2/TiO_2	Fe_2O_3/K_2O
SGS1	6.95	0.16	0.09	0.13	0.38	1.97	13.66	4.02
SGS2	11.25	0.13	0.07	0.07	0.33	1.75	19.70	4.42
SGS3	10.74	0.12	0.09	0.08	0.32	1.82	19.53	3.74
SGS4	12.40	0.17	0.08	0.09	0.32	1.96	24.26	3.76
SGS5	11.83	0.17	0.10	0.06	0.28	2.62	31.02	2.70
SGS6	13.16	0.22	0.15	0.16	0.34	3.05	40.08	2.31
SGS7	12.81	0.26	0.09	0.43	0.54	3.75	48.00	5.76
SGS8	24.81	0.18	0.05	0.22	0.37	3.15	78.23	7.47
SGS9	21.17	0.38	0.08	0.45	0.40	4.31	91.27	5.13
SGS10	37.63	0.52	0.10	0.13	0.15	11.02	414.75	1.58
SGS1A	12.82	0.20	0.11	0.12	0.41	3.03	38.78	3.74
SGS2A	15.12	0.23	0.08	0.38	0.44	3.46	52.23	5.47
SGS3A	17.10	0.18	0.07	0.21	0.37	3.31	56.57	5.32
SGS4A	18.86	0.35	0.07	0.40	0.39	3.90	73.57	5.57
SGS5A	38.44	0.54	0.10	0.13	0.13	11.00	423.00	1.41
SGS6A	10.24	0.14	0.09	0.11	0.28	1.90	19.42	3.20
SGS7A	11.25	0.13	0.07	0.07	0.33	1.75	19.70	4.42
SGS8A	10.74	0.12	0.09	0.08	0.32	1.82	19.53	3.74
SGS9A	12.40	0.17	0.08	0.09	0.32	1.96	24.26	3.76
SGS10A	11.83	0.17	0.10	0.06	0.28	2.62	31.02	2.70
Average	16.08	0.23	0.09	0.17	0.34	3.51	76.93	4.01

Paleosalinity and detrital influx

Fluvial swamps have relatively low (0.01%) P_2O_5 levels because increased P_2O_5 levels are typically found in dysaerobic water near the transition between oxic and anoxic conditions (Demaison and Moore, 1980). The influence of fluvial processes is indicated by the P_2O_5 values in the analyzed shales, which range from 0.02 weight percent to 0.09 weight percent (Table 1). The inflow of detrital material with low mineral concentrations may be the cause of the generally low P_2O_5 contents in the samples (Akinyemi et al., 2022).
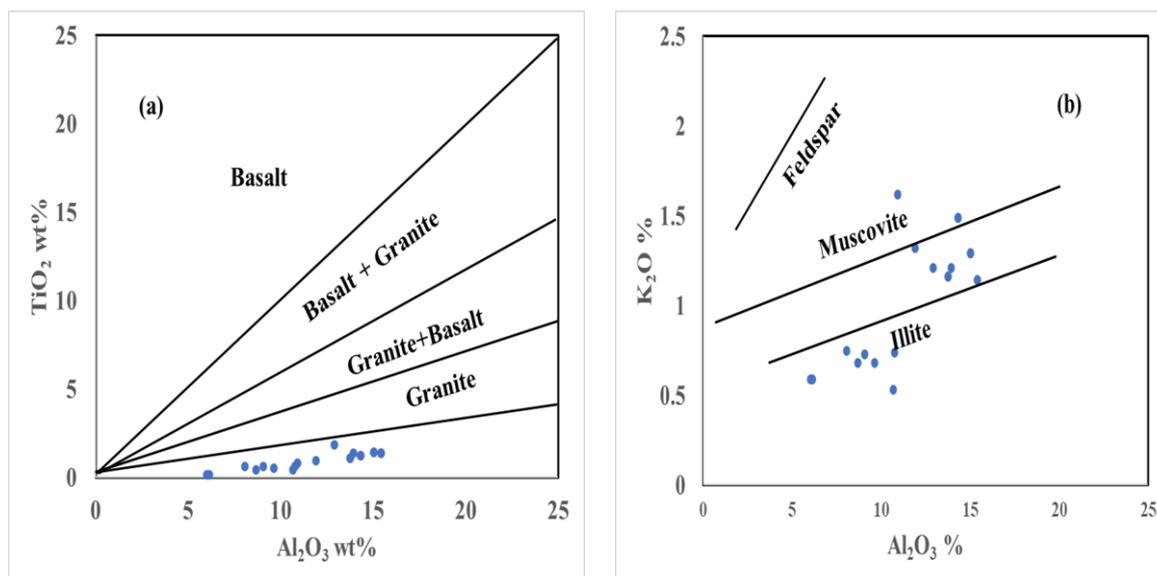
Figure 8: Cross plots of Al_2O_3 vs (a) TiO_2 (after Hayashi et al., 1997) and (b) K_2O (after Hayashi *et al*., 1997)
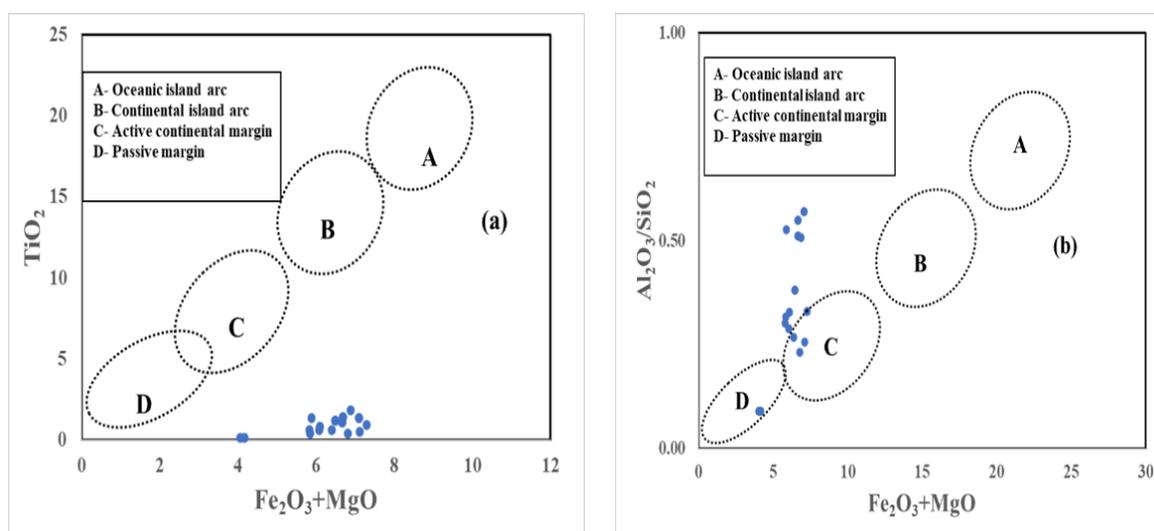
Figure 9: Cross plots of $Fe_2O_3 + MgO$ vs. (a) TiO_2 (after Bhatia., 1983) and (b) Al_2O_3/SiO_2 (after Bhatia, 1983) in the studied shales

CONCLUSION

SiO_2 has the highest concentration among the major oxides found, followed by $Al_2O_3 > Fe_2O_3 > SO_3 > MgO > CaO > SrO > BaO > K_2O > TiO_2 > Sb_2O_3 > CeO_2 > MnO$. The low values of the other oxides suggest that the shales were mostly formed of quartz minerals and were deposited in marine environments. The influence of fluvial processes was demonstrated by the low P_2O_5 values found in the examined shales. Furthermore, the sediments were formed from a mixture of felsic and mafic igneous rocks, as well as mixed compositional maturity, close to the active continental margin, according to the geochemical ratios calculated from the major oxides in the shales. This study showed that determining the provenance, tectonic conditions, and palaeosalinity of shale deposits may be accomplished effectively using the geochemical analysis of major oxides.

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