Statistical Technique as a Basin Analysis Tool: A Case Study of Bida and Enagi formations, Northern Bida Basin, Nigeria

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ABSTRACT

This study examines the significance of statistical technique in the evaluation depositional and weathering histories of siliciclastic sediments in the northern Bida Basin, Northcentral Nigeria. This study aims at employing the statistical analysis to characterize whole rock inorganic geochemical dataset obtained from x-ray fluorescence and inductive coupled plasma mass spectrometry to determine the elemental associations and consistent relation to interprete depositional history and provenance. 22 major oxides and trace elements from 78 representative samples collected from 16 outcrops from different locations were processed using factor analysis (FA) and principal component analysis (PCA). Interpretation from FA identified 2 major distinct groups for major oxides; group 1 with very strong to strong correlations of S_iO_2 and MgO, Fe_2O_3 with Al_2O_3 which might indicate quartz abundance while group 2 with moderate to weak negative correlations of MnO, CaO, $Na2_O$, K_2O, TiO_2 and P_2O_5 might indicate minor contributions from clays. Strong and moderate correlations of some trace elements including; Sc, Co, Zr, Nb, Hf, Th, V, Rb, Sr, Ba, Ni and Co may probably indicate contributions of heavy minerals. PCA results also displayed two different geochemical systematic trends; PC1-PC3 with eigen values greater than 1.0 (77.18%). This probably suggest prevalence of weathering, depositional conditions and diagenesis while PC4-PC9 with eigenvalues lesser than 1.0 (22.82%) suggest minimal contributions of clay minerals. For the trace elements, 2 packages were also indicated; PC1-PC3 group with greater eigenvalues than 1.0 (78.94%) which also indicate processes including sedimentary processes while PC4-PC14 group with eigen values less than 1.0 (21.06%) has minimal contribution probably from clay minerals. This study concludes that the application of the statistical technique using key elements for differentiation is useful for basin evaluation.

Keywords: Siliciclastic, Geochemistry, Factor Analysis, Principal Component Analysis, Depositional History, Provenance.

INTRODUCTION

Distribution of elements in clastic sedimentary rocks is largely governed by the geological processes (Spencer *et al.,* 1968; Bhatia, 1983; Roser and Korsch, 1986 and 1988; Hayashi *et al.,* 1997), therefore, its geochemical signatures would provide important information on tectonics influence over depositional system. Evidences to these have been affirmed in several plotting involving relationships of major oxides and trace elements and their ratios. For example, Herron (1988) employed bivariate plot of $\log(Fe_2O_3/K_2O)$ versus $\log(S_iO_2/Al_2O_3)$ for siliciclastic sediments' classification, McLennan et al. (1993) and Garcia et al. (1994) used Zr/Sc versus Th/Sc and Al_2O_3-Zr-TiO_2 plots to evaluate compositional trend of clastic sediments, Th/Sc versus Zr/Sc plot utilized by McLennan *et al.* (1993) for determining sediments' maturity, plots of Th/U versus Th with La versus Th after McLennan *et al.* (1993), and S_iO_2 versus (Al_2O_3+Na_2O+K_2O) after Suttner and Dutta (1986) to monitor the rate of chemical weathering and paleoclimatic conditions, while provenance studies by Condie (1993) employed plots of Th/Sc versus Sc and La/Th versus Hf, whereas, to unravel paleotectonic settings, plots of $\log(K_2O/Na_2O)$ versus S_iO_2 after Roser and Korsch (1986), T_iO_2 versus (Fe_2O_3+MgO) after Bhatia (1983), S_iO_2/Al_2O_3 versus K_2O/Na_2O after Roser and Korsch (1988), La/Y versus Sc/Cr after Bhatia and Crook (1986), and S_iO_2/20-(K_2O+Na_2O)-(TiO_2+Fe_2O_3+MgO) after Kroonenberg (1994) were adequately utilized.

Elemental assemblages associated with geological processes among the geochemical data sets require thorough evaluation, because elements involved in the process's changes may appear in more than one component, or several elements may be placed on the

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same component in a particular process. Several authors including Reimann *et al.* (2002), Pearce *et al.* (2005), Ali *et al.* (2006), Svendsen *et al.* (2007) and Pe-Piper et al. (2008) had submitted that application of multidimensional data sets is the best in determining element associations and to extract unobservable quantities hidden in the original measurements. Dimensionality reduction analysis is a Statistical or a Machine Learning technique of reducing a large number of variables into fewer numbers of factors by extracting maximum common variance from all variables and puts them into a common score (Turk and Pentland, 1991). It is important in many applications related to geology, engineering and geophysics (Reyment and Savazzi, 1999; Kaźmierczuk and Jarzyna, 2006), chemistry (Chiang et al., 2000), data mining (Tharwat *et al.,* 2012; Bramer, 2013), bioinformatics (Saeys *et al.*, 2007), and information retrieval (Venna et al., 2010). According to Tenenbaum *et al.* (2000), Kirby (2000), and Duda *et al.* (2012), approaches of the dimensionality reduction techniques are two; the supervised (Mixture Discriminant Analysis-MDA, Neural Networks-NN, and Linear Discriminant Analysis-LDA) and unsupervised approaches (Independent Component Analysis-ICA, Locally Linear Embedding-LLE, and Principal Component Analysis-PCA). These methods focus on explaining and summarizing the underlying variance (covariance) structure of a large set of variables through a few linear combinations of these variables. Principal Component Analysis (PCA) technique, a classical descriptive multivariate statistical method, is one of the most famous unsupervised dimensionality reduction techniques useful for process discovery in geochemical data (Jolliffe, 2011; Barshan *et al.,* 2011). The technique which was invented by Pearson (1901) and developed subsequently by Hotelling (1933) to identify underlying constructs or factors that explain the correlations among a set of items. It also summarizes a large number of items with a smaller number of derived items, called factors by capturing the highest amount of variation that is present in the data set to display graphically. Though, FA too, like PCA, is a multivariate statistical method that describes the data sets in terms of correlations structures that fit a pre-defined number of components (factors) by reducing such a large number of variables into fewer numbers of factors to explain variability among observed random variables in terms of fewer unobserved random variables called factors (Malinowski, 2002; Filzmoser *et al.,* 2009).

The northern Bida sub-Basin, which is the focus of this study, is composed of Campano-Maastrichtian siliciclastic sediment with different facies including conglomerates, sandstones, siltstones, and claystones (Adepoju et al., 2021). The data set used in this study contains 78 sandstone samples of bulk inorganic geochemical analyses from 16 outcrops within Northern Bida Basin, north-central, Nigeria. This research aims at testing the application of statistical techniques in distinguishing elemental associations of the siliciclastic sediments of the Bida and Enagi formations in order to interpret the associations in terms of geochemical data sets. This data set will be analyzed using multivariate analysis (Covariance Matrix, Factor and Principal Component Analysis) to infer the complex interacting sedimentary geological processes that underlie element distributions during deposition in the Bida Basin. This will also show the potential of the method for a better understanding of the complexity of factors that forced environmental dynamics and the way in which they were registered in sedimentary packages.

2. Geological Setting

The geological development of Bida Basin had been postulated by King (1950) and Kennedy (1965) as connected with South American and African plates' drifting apart during Gondwana break-up. Using ground survey and aeromagnetic research, Adeniyi (1985) proposed a wrench movement for the basin and this is connected with transform fault systems that led to the formation of basins and sub-basins throughout the whole Benue Trough as well as in nearby locations like the Bida Basin. Whiteman (1982) and Braide (1992) expressed differing views and proposed, pull-apart and cratonic sag as the origin of the Basin. They held that Bida Basin was formed during the Benue Trough tectonic evolution, which initiated as a triple-junction rift, with the opening of Gulf of Guinea in the late Jurassic to early Cretaceous.

Stratigraphically, four mappable units make up the stratigraphic framework of the northern Bida sub-Basin, and these may be observed as equivalent laterally to the successions in the southern Bida sub-Basin. The stratigraphic successions illustrating a correlation between the northern and southern portions of the Basin based on lithologic and depositional parameters is presented in figure 1. In the northern Bida sub-Basin, the Bida Formation, according to Adeleye (1972), is the oldest and made up of the Doko member at the base (mostly pebbly, sub-arkosic, and quartzose sandstones), which was deposited in a braided environment, and, the Jima member at the top (cross-stratified quartzose sandstones with mudstones) was deposited in a fluvial environment with lesser energy. Adeleye (1973) proposed a channel margin condition in tropical to sub-tropical climates. Adeleye (1972) submitted that Bida Formation underlays Sakpe Ironstone Formation which composed dominantly of ironstones (though with localized sandy-claystone at the basal part) indicated changes in facies rapidly throughout the basin. According to Adeleye (1973), Wuya (about 5 m thick, mainly pisolitic, with local sandstone at the base) and Baro (oolitic types with ferruginous, pyritic and concretionary sandstone) are the two members of the Sakpe Formation. The Enagi Formation which overlies the

Sakpe Ironstone consists primarily of siltstone-sandstone intercalation and claystone is laterally equivalent to the Patti Formation in the southern Bida Basin, according to Adeleye (1973). The Batati Formation, which is serving as the capping unit in the northern Bida sub-Basin is laterally equivalent to the Agbaja Formation in the southern Bida sub-Basin. Like Sakpe Formation, it is also composed dominantly of ironstones (though oolitic and goethitic) and with tiny amounts of argillaceous materials which was produced at nearshore shallow marine to the freshwater environment according to Adeleye (1973).

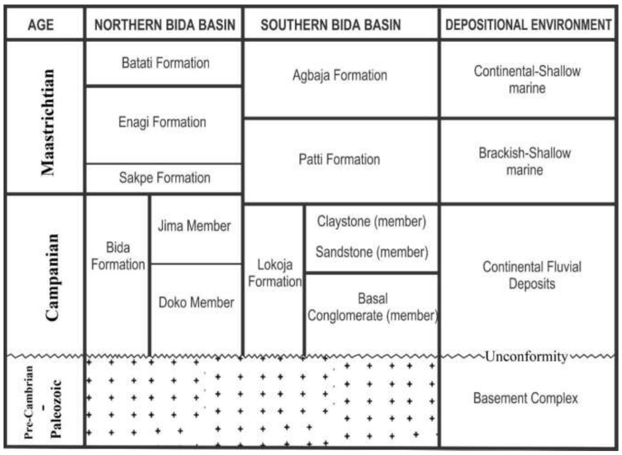

Figure 1: Regional stratigraphic successions in the Bida Basin (Modified after Ojo and Akande, 2012).

Analytical Methods

Sample collection, Preparation and Analysis

A representative 50-100g piece of each selected sample was crushed and pulverized into a fine powder using a mortar agate tool, then analyzed for major oxides (for S_iO_2, Al_2O_3, Fe_2O_3, K_2O, CaO, MgO, MnO, Na_2O, T_iO_2 and P_2O_5) using x-ray fluorescence (XRF) analysis and trace elements (for Sc, Co, Zr, Nb, Hf, Th, U, Y, V, Rb, Sr, Ba, Ni and Co) by total digestion (fusion followed by HF+HNO3 digestion) using Laser Ablation Multicollector Inductive Coupled Mass Plasma Spectrometer (LAM-MC-ICPMS). Total of forty-six (46) samples were selected for major oxides (Table 1a) whereas seventy-eight (78) samples were analyzed for trace elements (Table 1b), all at National Geophysical Research Institute (NGRI), Hyderabad, India.

Statistical Analysis

The raw chemical data sets were subjected to statistical analysis to determine elemental associations in order to identify and explain the variance within the data sets. The multivariate statistical analysis (Factor Analysis and Principal Component Analysis) was done using the SPSS software (SPSS Inc., Chicago, IL, USA). The chemical data sets were first subjected to Correlations Matrices (Pearson) to identify associations, then analyzed with multivariate analysis to infer the complex interacting causes that underlie element distributions in sediments.

Results Presentations and Discussions

Correlations Matrix (Pearson)

Results of variables and factors extracted from analyzed samples using Pearson correlations matrix to designate covariant groups of elements are presented in Tables 1a and b. The highly correlated elements groups and their relationship were then used to deduce the important geological factors influencing the elements.

Major Oxides

Forty-six (46) were observed for major oxides, the results (Table 2a) revealed a strong negative correlation of SiO2 with Al_2O_3 (r = -0.668), and Fe_2O_3 (r = -0.673) but weak negative correlations with MgO (r = -0.342) which may point to an abundance distribution of quartz minerals within the Basin. Also, strong positive correlations of MnO with T_iO_2 (r = 0.732) may indicate contribution of phyllosilicates (e.g. rutile). Suggestions of contributions of clay minerals into the sediments might be affirmed by the strong positive correlations of MgO with CaO (r = 0.791), K_2O (r = 0.717), and Na_2O (r = 0.747), strong positive correlations of CaO with Na_2O (r = 0.749), and K_2O (0.550), as well as the strong positive correlations of Na_2O with K_2O (0.749). The Pearson correlations matrix results of major oxides as discussed above generally indicated negative correlations trend of S_iO_2 with other major oxides and this indicate presence of bulk of S_iO_2 (as quartz grains) within the environments of study. This can be interpreted that the Basin received detritus primarily from continental sources.

Trace Elements

For the trace elements, results of observations of variables on seventy-eight (78) analyzed samples (Table 2b) showed a very strong positive correlations of Sc with U (r = 0.809), with strong positive correlations with Nb (r = 0.689), Y (r = 0.673), Zr (r = 0.663), Hf (r = 0.651), Th (r = 0.649), and V (r = 0.634) but moderate positive correlations with Co (r = 0.450). Also, Co has strong positive correlations with U (r = 0.628), moderate positive correlations with Ba (r = 0.461), and Y (r = 0.419), but weakly positively correlated with Th (r = 0.361), V (r = 0.343), Nb (r = 0.342) and Zr (r = 0.315). Nb has a strong positive correlation with Th (r = 0.714), Hf (r = 0.712), Y (r = 0.701), and U (r = 0.616), but positively moderately correlated with V (r = 0.460). Also, Hf show very strongly correlated with Th (r = 0.839), strongly with Y (r = 0.739) and U (r = 0.680) but moderately correlated with V (r = 0.620). The relationships of Sc, Co, Zr, Nb, and Hf might probably indicate measurements for compositional trend and maturity studies.

Table 1a: Major Oxides (%) data of samples from Northern Bida Basin.

Sample No	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
AGB-1B	88.50	7.84	1.67	0.00	0.02	0.05	0.04	0.12	0.33	0.04
AGB-1D	74.98	18.38	3.82	0.01	0.07	0.05	0.07	0.24	1.22	0.07
AGB-1G	82.09	14.71	1.59	0.01	0.05	0.01	0.08	0.50	1.41	0.06
AGB-1K	79.89	13.02	4.18	0.02	0.05	0.05	0.03	0.05	1.00	0.12
BDA-1A	84.68	11.25	1.84	0.00	0.01	0.01	0.02	0.01	0.23	0.02
BDA-1B	88.54	8.37	1.37	0.01	0.01	0.01	0.02	0.02	0.32	0.02
BDA-1D	89.22	7.29	1.52	0.01	0.00	0.02	0.02	0.01	0.28	0.01
BDA-1K	86.04	6.32	3.17	0.04	0.02	0.02	0.02	0.01	4.89	0.04
BDA-1R	87.55	8.12	2.28	0.01	0.01	0.01	0.02	0.01	0.40	0.02
DOK-1D	78.74	14.25	5.21	0.01	0.04	0.02	0.02	0.03	0.92	0.03
DOK-1F	80.04	15.52	2.06	0.01	0.02	0.03	0.02	0.03	0.28	0.03
DOK-1K	85.36	10.47	2.56	0.01	0.01	0.02	0.02	0.01	0.30	0.03
DOK-1X	87.91	9.24	0.67	0.00	0.01	0.01	0.02	0.01	0.30	0.03
ENG-1B	87.26	9.40	1.89	0.01	0.06	0.16	0.22	1.31	0.57	0.02
ENG-1E	89.63	7.14	1.48	0.00	0.02	0.03	0.08	0.97	0.25	0.02
ENG-1J	90.88	4.74	1.83	0.01	0.00	0.01	0.07	0.85	0.17	0.02
ENG-1L	84.98	9.51	4.18	0.01	0.05	0.05	0.08	0.88	0.40	0.02
ENG-1N	86.26	7.13	4.52	0.01	0.02	0.02	0.06	0.66	0.47	0.02
ENG-1V	92.44	6.07	1.21	0.01	0.01	0.04	0.03	0.14	0.75	0.02
GBL-1A	75.56	12.08	2.97	0.01	0.20	0.11	0.11	2.90	0.27	0.01
GBL-1C	84.44	8.90	1.28	0.01	0.02	0.01	0.02	0.77	0.25	0.01
GBL-1D	85.25	7.83	2.44	0.01	0.03	0.02	0.01	0.14	0.58	0.01
GBL-1E	79.44	9.06	2.31	0.01	0.39	0.21	0.12	3.24	0.18	0.01
GBU-1A	75.51	13.36	2.99	0.01	0.06	0.01	0.04	1.40	0.32	0.01
GBU-1B	87.07	6.36	1.15	0.01	0.07	0.01	0.06	1.61	0.28	0.01
GBU1D	90.59	4.65	0.76	0.01	0.02	0.01	0.06	1.61	0.18	0.01
KJT-1A	86.32	9.78	1.75	0.01	0.05	0.08	0.09	0.95	0.60	0.01
KJT-1C	85.65	7.17	3.39	0.02	0.11	0.19	0.17	2.16	1.12	0.02
KJT-1F	83.96	8.25	4.55	0.01	0.40	0.37	0.17	1.80	0.32	0.02
KJT-1J	88.83	7.26	1.54	0.00	0.06	0.17	0.07	0.81	0.20	0.02
KJT-1Q	86.65	9.72	1.05	0.00	0.01	0.04	0.10	1.30	0.37	0.01
KUD-1A	83.41	7.95	2.57	0.01	0.05	0.03	0.01	0.08	1.34	0.02
KUD-1B	74.98	10.10	7.56	0.01	0.06	0.03	0.01	0.09	1.35	0.07
KUD-1C	87.93	7.46	0.89	0.01	0.04	0.04	0.01	0.05	1.00	0.02
KUD-1F	82.39	7.45	4.73	0.01	0.06	0.02	0.01	0.06	1.53	0.03
KUT-2A	90.93	4.15	2.01	0.01	0.02	0.03	0.01	0.04	0.37	0.04
KUT-2G	89.59	5.35	2.06	0.01	0.03	0.02	0.01	0.04	0.35	0.02
KUT-2K	89.60	5.35	1.58	0.01	0.04	0.04	0.01	0.04	0.51	0.02
PTG-1A	88.25	5.52	1.75	0.01	0.05	0.01	0.04	1.31	0.19	0.01
PTG-1B	87.08	4.98	4.03	0.01	0.04	0.01	0.01	0.26	0.27	0.01
PTG-1D	68.69	7.04	17.57	0.02	0.05	0.02	0.01	0.17	0.50	0.01
PTG-1E	79.57	9.87	1.90	0.01	0.27	0.16	0.14	2.91	0.37	0.01
RAB-1F	90.84	5.62	3.16	0.01	0.04	0.06	0.08	0.53	0.12	0.02
RAB-1H	88.92	7.01	1.84	0.01	0.08	0.26	0.10	0.66	0.30	0.11
RAB-1P	85.62	9.65	2.56	0.01	0.19	0.16	0.07	0.53	0.27	0.08

There is also a very strong positive correlations of element Zr with Hf (r = 0.990), and Th (r = 0.836), strong positive correlation with Y (r = 0.751), Nb (r = 0.720), and positive moderate correlations with U (r = 0.692). Element Th is strongly correlated with Y (r = 0.798), and U (r = 0.702) but moderate positive correlation with V (r = 0.508), meanwhile, has weak positive correlations with (r = 0.460). Strong correlations of element U with Y (r = 0.734) and moderate positive correlation with V (r = 0.493) were also recorded. The above relationships might probably indicate elemental contributions of heavy mineral which is a good tool for provenance and paleotectonic settings studies.

The strong positive correlations of Rb with Ba (r = 0.721), Sr (r = 0.652) and Sr with Ba (r = 0.800) and moderately with Y (r = 0.496) suggest that they are good tools for determining weathering, and depositional environment. Also, very strong positive correlations of Ba with Rb (r = 0.92), and Sr (r = 0.72) may indicate contributions of clay mineral contents and this can be supported by the positive correlations of Nb with Sc (r = 0.71), Zr (r = 0.95), Hf (r = 0.94), Th (0.83) and Y (r = 0.77).

Table 1b: Trace elements composition (ppm) data of samples from Northern Bida Basin.

Sample No	Sc	Co	Rb	Sr	Zr	Nb	Ba	Hf	Th	U	Y	Cr	Ni	V
AGB-1B	3.91	3.67	4.91	27.83	137.00	8.33	52.80	4.36	7.33	0.83	9.45	382.13	26.77	13.87
AGB-1D	9.92	5.37	10.33	53.01	499.64	26.89	106.39	15.77	17.86	2.72	26.95	341.34	66.23	17.12
AGB-1G	8.45	3.91	11.41	37.01	784.11	27.36	124.12	24.10	17.22	2.79	32.72	238.22	53.82	14.06
AGB-1K	6.46	5.04	2.46	76.19	596.80	22.82	91.17	17.89	12.84	2.45	28.37	314.03	60.55	14.42
BAR-1D	2.13	1.70	14.92	6.53	186.40	4.21	140.90	7.39	6.84	1.38	11.08	14.25	11.11	4.03
BAR-1F	2.64	1.48	2.62	3.27	121.80	5.01	30.34	4.39	7.27	1.29	10.17	14.07	14.99	3.22
BAR-1H	3.84	1.44	3.40	2.04	72.25	3.73	27.69	3.43	4.01	1.33	11.08	23.00	18.56	5.02
BAR-1J	1.77	1.03	2.32	4.50	191.90	5.73	32.76	5.51	7.90	1.88	7.50	13.54	27.33	22.19
BDA-1A	3.30	3.37	1.88	6.63	166.29	6.37	29.59	5.26	5.88	0.82	5.74	258.88	24.55	13.38
BDA-1B	3.20	3.54	2.00	5.13	228.83	7.96	32.54	7.17	8.73	1.16	6.44	349.14	21.38	13.80
BDA-1D	3.05	4.31	1.88	4.72	304.71	7.23	25.47	9.03	8.25	0.97	4.59	390.01	20.18	14.94
BDA-1K	14.79	5.78	2.27	6.82	2527.15	86.87	50.45	75.60	72.75	8.03	44.60	335.42	89.23	13.98
BDA-1R	4.29	3.78	1.74	4.41	231.37	9.56	17.37	7.20	10.46	1.10	5.49	248.92	45.03	13.34
DOK-1D	5.49	3.52	2.59	7.79	874.86	16.61	30.97	25.61	18.99	2.83	17.89	189.74	54.37	13.19
DOK-1F	3.26	3.52	1.70	11.48	130.60	4.93	37.38	4.03	6.28	1.04	4.46	341.42	19.17	13.61
DOK-1K	2.76	3.92	1.97	9.07	114.95	5.20	31.53	3.68	5.29	0.97	3.12	269.05	21.78	12.27
DOK-1T	2.74	3.24	1.79	9.28	150.79	6.30	27.16	4.87	6.76	0.86	2.60	225.45	27.62	11.94
DOK-1X	2.94	2.80	1.20	11.16	247.84	6.51	35.66	7.72	7.60	1.17	5.71	223.67	15.75	11.28
ENG-1B	4.21	4.60	37.42	39.59	421.01	15.39	335.07	12.33	15.32	1.95	14.95	321.70	24.54	13.74
ENG-1E	2.69	3.13	27.36	24.24	181.18	7.09	223.39	5.66	10.28	1.40	9.38	238.40	18.27	12.67
ENG-1H	5.89	3.34	16.82	14.94	353.08	12.45	120.24	10.58	11.57	2.35	18.74	224.88	44.33	12.68
ENG-1J	2.55	3.05	22.78	18.33	154.39	4.53	149.88	4.48	5.93	1.25	9.89	317.19	19.80	12.99
ENG-1L	4.75	3.05	24.05	20.78	271.19	9.50	211.03	8.19	9.61	1.95	10.44	198.60	37.19	12.90
ENG-1N	4.44	7.29	18.24	17.15	471.07	11.97	157.58	14.28	15.77	3.05	16.40	236.16	27.80	13.92
ENG-1V	4.49	2.78	5.50	10.48	902.83	18.06	74.87	26.61	20.59	3.44	30.99	331.16	25.43	12.27
GBL-1A	2.30	2.40	11.20	14.70	1.70	0.03	72.70	0.04	4.60	0.50	6.44	12.20	18.00	3.70
GBL-1C	1.60	1.20	2.10	1.70	1.20	0.02	31.10	0.04	5.20	0.40	5.54	9.80	6.00	3.30
GBL-1D	2.90	1.70	1.90	3.00	3.80	0.03	29.40	0.12	14.20	0.80	5.61	13.30	20.00	5.80
GBL-1E	1.50	4.50	7.80	30.70	0.40	0.02	129.00	0.02	4.00	0.30	14.46	5.90	3.00	5.10
GBU-1A	3.30	1.20	6.90	2.00	3.60	0.02	28.80	0.12	7.00	0.40	2.50	12.50	23.00	3.90
GBU-1B	2.50	1.40	6.10	2.70	2.80	0.02	29.50	0.06	7.90	1.40	8.18	8.70	9.00	2.40
GBU-1D	1.30	0.90	3.00	1.80	1.70	0.03	15.70	0.04	4.60	0.60	3.13	8.40	3.00	2.90
JIM -1B	3.79	2.33	4.50	2.46	548.70	12.33	62.83	21.12	18.04	2.98	22.07	367.10	22.54	8.37
JIM -1L	4.77	4.23	2.57	11.09	105.69	6.72	28.99	3.39	7.78	1.79	18.46	267.14	36.03	13.45
JIM -1N	8.92	4.07	4.58	9.83	1022.05	23.37	59.80	29.32	23.21	4.15	28.26	219.78	76.01	12.97
JIM -1R	3.07	4.21	1.53	6.17	158.98	7.38	26.90	4.88	5.20	0.89	3.51	312.02	20.25	13.07
JIM -1X	3.93	4.00	1.47	6.56	442.78	11.69	38.49	12.83	7.96	1.47	6.23	342.75	20.43	13.37
KJT-1A	3.69	4.20	21.83	32.44	578.21	14.55	332.57	17.38	12.49	2.93	17.15	306.87	25.22	13.90
KJT-1C	4.58	7.98	51.84	77.20	716.63	23.90	696.22	21.54	50.21	5.59	42.79	453.85	30.03	13.92
KUD 1C	1.40	0.70	0.70	3.10	9.80	0.02	17.50	0.24	6.20	0.27	3.10	8.60	8.00	1.80
KUD-1A	3.50	1.00	1.90	3.60	15.40	0.09	19.70	0.36	10.10	0.89	5.67	22.60	30.00	3.10
KUD-1B	4.90	1.70	2.80	4.10	18.90	0.12	15.20	0.42	12.30	1.66	5.99	78.40	90.00	5.00
KUD-1F	2.40	0.70	1.60	2.20	18.40	0.09	14.50	0.48	11.00	0.62	4.26	22.30	36.00	2.50
KUT 2A	2.00	2.00	1.30	2.20	5.50	0.15	18.20	0.13	7.50	1.14	4.38	13.20	15.00	4.40
KUT 2G	2.40	1.80	1.10	1.40	5.90	0.10	7.00	0.16	6.20	0.94	2.16	14.40	18.00	3.50
KUT 2K	2.30	1.20	1.20	2.30	5.20	0.05	9.40	0.16	8.00	0.87	4.17	15.20	16.00	2.90
KUT 2P	4.80	1.50	1.30	2.90	9.70	0.02	10.70	0.24	14.70	1.59	8.57	42.10	44.00	3.50
KUT 2Q	3.50	0.60	1.90	3.20	5.40	0.02	11.80	0.15	9.70	1.91	13.54	22.00	30.00	1.60
KUT -2D	1.40	1.50	1.30	1.10	3.50	0.08	5.50	0.09	3.60	0.92	0.95	8.00	9.00	4.10
LEM -1A	4.25	4.11	17.69	18.14	445.01	12.89	162.19	13.57	13.08	2.28	17.67	332.39	29.21	13.63
LEM -1C	5.97	3.32	6.98	29.76	559.09	14.79	121.21	16.86	20.60	2.62	31.71	174.34	51.34	12.36
LEM -1E	2.25	3.53	15.84	5.80	199.70	4.68	118.30	6.10	5.48	1.90	6.57	1265.00	13.95	13.59
LEM -1G	5.41	4.33	7.18	10.83	334.51	11.89	66.22	9.90	13.87	2.46	12.40	235.44	39.31	13.67
LEM -1H	3.36	13.62	11.68	4.77	124.50	5.60	172.20	4.54	6.73	3.28	13.26	418.30	15.18	39.56
LEM -1P	3.75	12.99	9.95	3.74	512.00	11.89	91.84	18.15	26.78	7.77	21.10	255.20	24.58	25.20
PAT-1B	3.72	2.89	10.53	13.93	217.21	8.23	100.10	6.82	8.85	1.61	7.54	255.68	30.82	11.76
PAT-1G	5.30	3.62	2.60	5.02	256.82	9.68	36.05	8.48	15.78	2.98	11.17	185.29	35.68	11.15
PAT-1J	18.00	15.28	1.92	1.17	782.20	12.18	168.40	26.44	19.44	14.21	28.60	1056.00	12.15	2.53
PAT-1M	3.08	3.89	1.31	0.91	48.65	1.81	22.99	2.02	3.34	1.26	2.45	698.40	13.59	15.02
PAT-1N	6.21	15.77	2.07	0.97	481.50	10.26	127.90	15.93	13.57	4.39	18.23	259.60	16.97	32.54
PTG-1A	1.50	1.40	9.60	2.00	2.90	0.03	25.10	0.08	8.10	0.80	5.07	8.40	11.00	3.40
PTG-1B	1.60	1.10	5.20	1.40	4.90	0.03	24.10	0.13	15.20	1.70	4.54	15.80	33.00	2.70
PTG-1D	2.90	3.30	6.10	2.70	9.80	0.15	18.90	0.26	17.20	5.10	1.23	88.20	176.00	5.80
PTG-1E	1.90	1.60	7.50	20.50	1.10	0.02	91.00	0.03	5.40	0.90	6.81	9.60	12.00	3.10
RAB-1E	3.64	4.71	19.22	28.21	154.30	4.14	237.12	6.75	2.72	2.09	8.09	309.76	15.78	13.22
RAB-1F	3.34	3.07	14.94	17.82	60.21	2.98	152.94	2.08	3.06	1.06	5.02	315.40	23.41	14.88
RAB-1H	3.21	3.10	16.93	26.58	146.83	7.02	179.50	4.71	3.82	1.17	6.33	301.67	24.84	13.27
RAB-1L	4.24	3.16	17.31	33.71	453.15	16.41	190.65	14.28	11.14	1.99	9.81	229.15	30.54	10.93
RAB-1P	3.35	3.31	16.40	22.00	110.60	6.95	159.62	3.23	3.87	0.78	5.54	299.05	29.14	13.10
SHG-1B	2.70	3.39	3.57	7.38	95.27	4.54	37.34	3.10	3.37	0.64	4.00	370.65	18.15	13.78
SHG-1F	2.63	2.26	2.63	6.82	102.79	5.03	34.63	3.13	4.55	0.62	4.04	273.56	19.93	12.76
SHG-1K	2.54	3.03	4.16	6.92	139.59	5.62	43.83	4.73	4.39	1.08	7.10	397.77	22.31	14.60
SHG-1P	3.41	2.91	2.75	4.99	339.87	11.87	31.48	10.38	6.75	0.88	7.17	329.03	23.57	13.54
SHG-1X	5.48	4.02	4.02	7.82	687.68	10.67	54.15	20.88	10.74	1.36	12.70	415.06	40.21	15.80
TAN-1A	3.10	3.47	1.31	3.13	101.94	2.84	26.51	3.52	2.88	1.41	4.70	247.03	12.55	12.58
TAN-1C	4.44	3.93	20.48	23.44	327.14	9.01	199.46	9.80	12.37	2.10	8.77	218.93	29.91	12.36
TAN-1D	3.21	2.27	22.32	20.35	140.24	6.40	175.82	4.57	4.31	2.33	3.93	230.78	18.98	11.76

Factor Analysis and Principal Component Analysis

The elemental relationships observed in the major and trace elements from the Pearson correlations matrix results were further studied using Factor Analysis and Principal Component Analysis to identify element associations within the data sets. According to Gabriel (1971), Zhou *et al.* (1983), Davis (2002), Principal Components (PCs) are formed on the basis of an eigen analysis of the data. The eigen values represent the relative significance of each linear combination of variables (elements) that make up the eigenvectors and are typically provided in descending order so that each successive PC (e.g., PC1 vs. PC2) accounts for a decreasing amount of the overall variability of the data. Graphical displays are generally the most effective at viewing the results of a PCA. By extracting eigen vectors and eigen values from the correlation's matrix, the number of main significant components and the

Table 2a: Pearson Correlations matrix for Major oxides of the analyzed samples.

Variables	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2
SiO_2	**1.000**								
Al_2O_3	* -0.668	**1.000**							
Fe_2O_3	* -0.673	0.085	**1.000**						
MnO	-0.227	-0.070	0.353	**1.000**					
MgO	** -0.342	0.135	0.095	0.056	**1.000**				
CaO	-0.059	0.022	0.000	0.005	*0.791	**1.000**			
Na_2O	-0.033	0.119	-0.110	-0.042	** 0.588	*0.747	**1.000**		
K_2O	-0.200	0.031	-0.107	-0.033	*0.717	**0.550	*0.749	**1.000**	
TiO_2	-0.163	0.087	0.141	*0.732	-0.100	-0.115	-0.132	-0.228	**1.000**

*** Very strong and strong correlations; ** Moderate and weak correlations**

Table 2b: Pearson Correlations matrix for Trace elements of the analyzed samples.

Variables	Sc	Co	Rb	Sr	Zr	Nb	Ba	Hf	Th	U	Y	Cr	Ni	V
Sc	**1.000**													
Co	**0.450	**1.000**												
Rb	0.106	0.233	**1.000**											
Sr	0.208	0.226	*0.653	**1.000**										
Zr	*0.663	**0.315	0.052	0.104	**1.000**									
Nb	*0.689	**0.342	0.050	0.228	*0.720	**1.000**								
Ba	0.178	**0.461	*0.721	*0.800	0.175	0.145	**1.000**							
Hf	*0.651	0.295	0.064	0.110	*0.990	*0.712	0.185	**1.000**						
Th	*0.649	**0.361	0.191	0.214	*0.836	*0.714	0.299	*0.839	**1.000**					
U	*0.809	*0.628	0.197	0.187	*0.692	*0.616	**0.306	*0.680	*0.702	**1.000**				
Y	*0.673	**0.419	**0.290	**0.496	*0.751	*0.701	**0.464	*0.739	*0.798	*0.734	**1.000**			
Cr	0.203	0.168	0.123	0.092	0.194	0.080	0.188	0.205	0.040	0.186	0.079	**1.000**		
Ni	0.087	0.101	0.099	0.006	-0.066	-0.035	0.025	-0.079	0.154	0.180	-0.004	-0.205	**1.000**	
V	*0.634	**0.343	0.192	0.247	**0.460	*0.620	0.153	**0.470	*0.508	**0.493	**0.490	0.249	-0.079	**1.000**

*** Very strong and strong correlations; ** Moderate and weak correlations**

percentage of total variance explain could be determined and interpretations would be made from the component loadings to give correlations between the component and the elements.

Factor Analysis (FA)

Major oxides

Factor Analysis, as presented in Table 3a, observed three (3) major elements associations (F1-F3) and they are discussed here in relation to their geological process significance.

Factor 1 (F1): F1 explained 34.341% of the total variance and has high loadings of greater than 0.75 (>0.75) for MgO, CaO, Na_2O and K_2O which suggest their importance in evaluating weathering process and unraveling depositional environments.

Factor 2 (F2): This factor is characterized by very high loadings of 0.75–0.50 with 24.606% of the total variance on S_iO_2, Fe_2O_3, MnO and T_iO_2 (S_iO_2 has higher but negative value), may indicate prevalence of effect of clay mineral factors and diagenesis.

Factor 3 (F3): F3 explained 16.228% of the total variance and also with loadings between 0.75 and 0.50 on Al_2O_3, MnO and $T_{i2}O$ which may also indicate significant contribution of clay mineral factors. It is also suggested that clay minerals have principally formed in the source area rather than as a result of weathering process and provenance indicators.

Trace Elements

Four factors (F1-F4) were observed with trace elements associations (Table 3b), and their geological importance are discussed.

Factor 1 (F1): The higher loadings for Sc, Zr, Nb, Hf, Th, U and Y (>0.75), relatively low loadings for Co and V (<0.75) accounted for 44.712% of total variance suggest a substantial contribution from more than one geological process but with one prevailing on the other. Elements with higher loadings is probably suggested to have contributions basically from heavy minerals while those with lower loadings might indicate discussions towards provenance process.

Factor 2 (F2): This factor is characterized by very high loadings of >0.75 on Ba, Rb and Sr with 16.644% of the total variance. The pattern of loadings suggests that Factor 2 may indicate discussions related to weathering process and depositional environment as the elements associated are pointing to weathering of minerals in continental environments. Presence of Rb could also possibly imply the presence of K-feldspar associated with the heavy mineral suite as a response to various physical sorting processes.

Factor 3 (F3): The F3 is characterized by very high loadings displayed by positive Ni and negative Cr strong loadings greater than 0.75 (>0.75) with 9.236% of the total variance and so designate as a provenance study.

Factor 4 (F4): This factor only explained 7.350% of the total variance with average strong positive loading lesser than 0.75 (<0.75) on Co and Cr which points more to discussions related to provenance and tectonic settings studies.

Principal Component Analysis (PCA)

Major oxides

Three statistically significant components (PC1-PC3) out of nine (9) PCs provides eigenvalues greater than 1.0 (>1.0), and accounted for 77.17% of the total variance in the data, whereas, remaining PCs (PC4-PC9) with eigenvalues lesser than 1.0 (<1.0) accounted for only 22.88% of the total variance. According to Hair Jr. et al. (2014), communality values above 0.6 indicate that the number of factors is acceptable and validates the factor model used. The communalities in the scree plot (Figure 2a) implies that over 75% of the variance is explained by the extracted 3 factors. From the figure, the first eigenvector constituted 31.62% of the total variance and

Table 3a: Factor loadings and other corresponding values of the Principal Component Analysis for Major oxides.

Factor loadings	F1	F2	F3	F4	F5	F6	F7	F8	F9
SiO_2	-0.312	*-0.808	0.463	-0.049	-0.114	0.065	0.046	0.083	0.079
Al_2O_3	0.213	0.458	** -0.617	-0.580	-0.102	0.050	0.109	0.031	0.052
Fe_2O_3	0.038	*0.729	-0.147	0.626	-0.076	0.199	-0.064	0.043	0.052
MnO	-0.043	**0.678	**0.659	0.023	0.117	0.004	0.301	0.005	-0.006
MgO	*0.894	0.104	0.065	0.093	-0.085	-0.387	-0.022	0.142	-0.006
CaO	*0.854	-0.087	0.214	0.058	-0.438	-0.001	0.040	-0.140	0.013
Na_2O	*0.855	-0.157	0.154	-0.150	0.018	0.433	-0.029	0.085	-0.043
K_2O	*0.855	-0.121	0.066	-0.002	0.488	-0.031	-0.048	-0.074	0.053
TiO_2	-0.207	**0.627	**0.576	-0.387	-0.058	-0.021	-0.279	-0.007	0.013
Eigenvalue	3.181	2.305	1.460	0.914	0.484	0.385	0.192	0.062	0.017
Variability (%)	34.341	24.606	16.228	10.160	4.378	4.279	2.134	0.689	0.186
Cumulative %	34.341	60.947	77.175	87.334	92.712	96.991	99.124	99.814	100.000
Controlling Elements	MgO, CaO, Na_2O & K_2O	SiO_2, Fe_2O_3, MnO & TiO_2	Al_2O_3, MnO & TiO_2	—	—	—	—	—	—
Controlling Processes	Weathering Process and Depositional Environment	Clay mineral distribution and Diagenesis	Weathering & Provenance	—	—	—	—	—	—

* Variables with >0.75 loadings; ** Variables with 0.75–0.50 loadings

Table 3b: Factor loadings and other corresponding values of the Principal Component Analysis for Trace Elements.

Factor Loadings	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
Sc	*0.828	-0.183	0.040	0.216	0.200	-0.063	-0.170	0.316	0.019	-0.171	0.124	-0.114	-0.035	-0.002
Co	** 0.565	0.222	0.114	** 0.550	-0.027	** 0.510	0.101	-0.176	0.016	-0.026	-0.052	-0.105	0.023	-0.003
Rb	0.317	*0.799	0.015	-0.075	-0.011	-0.194	0.372	0.195	0.183	0.046	-0.043	-0.063	-0.002	-0.001
Sr	0.411	*0.782	-0.054	-0.245	0.160	-0.053	-0.295	-0.055	-0.054	-0.079	-0.100	-0.026	0.139	0.001
Zr	*0.859	-0.328	-0.071	-0.191	-0.268	-0.025	0.078	-0.027	-0.013	-0.132	-0.108	-0.007	-0.018	0.064
Nb	*0.810	-0.248	-0.019	-0.137	0.259	-0.002	-0.105	-0.213	0.368	0.033	0.033	0.047	-0.018	-0.001
Ba	0.458	*0.818	-0.034	-0.050	-0.161	0.114	-0.032	-0.093	-0.061	-0.095	0.157	0.133	-0.117	0.002
Hf	*0.854	-0.319	-0.091	-0.205	-0.268	-0.045	0.099	-0.034	-0.027	-0.141	-0.090	0.017	-0.003	-0.064
Th	*0.872	-0.159	0.187	-0.192	-0.128	-0.081	0.133	-0.112	-0.102	0.107	0.223	-0.060	0.120	0.003
U	*0.857	-0.084	0.174	0.287	-0.079	0.102	-0.041	0.255	0.011	0.108	-0.047	0.206	0.079	0.002
Y	*0.892	0.073	0.055	-0.228	-0.025	0.080	-0.175	0.050	-0.103	0.252	-0.082	-0.090	-0.121	-0.005
Cr	0.232	0.093	** -0.673	** 0.484	-0.298	-0.362	-0.125	-0.084	0.032	0.075	0.014	-0.027	0.009	0.000
Ni	0.038	0.085	*0.831	0.288	-0.091	-0.423	-0.072	-0.143	-0.007	-0.028	-0.052	-0.003	-0.035	-0.001
V	** 0.668	-0.070	-0.219	0.163	** 0.576	-0.197	0.214	-0.112	-0.199	-0.003	-0.044	0.058	-0.028	0.002
Eigenvalue	6.400	2.330	1.293	1.029	0.755	0.692	0.409	0.347	0.239	0.179	0.139	0.107	0.073	0.008
Variability (%)	44.712	16.644	9.236	7.350	4.389	4.946	2.919	2.482	1.704	1.278	0.994	0.767	0.520	0.059
Cumulative %	44.712	62.356	71.592	78.942	84.331	89.277	92.196	94.678	96.382	97.659	98.654	99.421	99.941	100.000
Controlling Elements	Sc, Co, Zr, Nb, Hf, Th, U, Y & V	Rb, Sr & Ba	Ni & Cr	Co & Cr	V	Co	—	—	—	—	—	—	—	—
Controlling Process	Heavy Minerals and Provenance	Weathering and Leaching	Sorting and Maturity		Provenance		—	—	—	—	—	—	—	—

* Variables with >0.75 loadings; ** Variables with 0.75 –0.50 loadings

presented greater weights for MgO, CaO, Na_2O, and K_2O that are important in weathering process and depositional environment discussions. The second eigenvector presented 24.20% of the total variance and the greatest weights are for Al_2O_3, MnO, and T_iO_2 which are important sources of clay minerals and therefore useful for discussion on Diagenesis. The third eigenvector constituted 14.75% of the total variance and presented the greatest weights for weathering process and provenance.

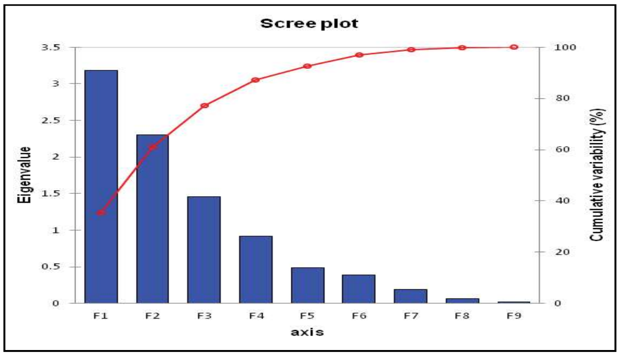

Figure 2a: Scree plot of final dataset for Major oxides in Northern Bida Basin.

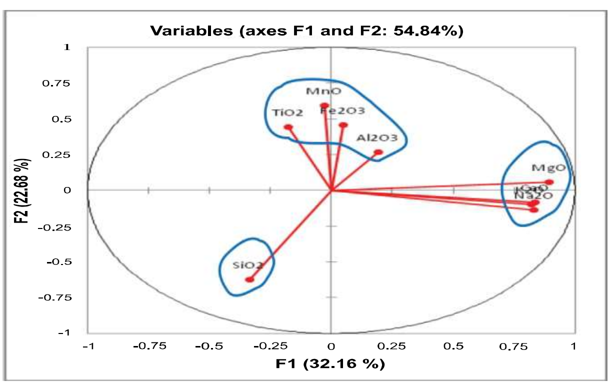

Figure 2b: Eigenvector plot of Major Oxides within Northern Bida Basin showing the grouping of elements of similar geological processes.

Trace Elements

As shown in figure 3a, the first four PCs (PC1-PC4), out fourteen (14) extracted PCs have eigenvalues of greater than 1.0 (>1), and therefore, accounted for 78.942% of the total variance in the data sets. This implies that over 75% of the variance is explained by the 4 PCs. The first eigenvector constituted 48.069% of the total variance and presented greater weights for Sc, Co, Zr, Nb, Hf, Th, U, Y, and V which are significant in heavy minerals sources, therefore, in provenance studies. The second eigenvector presented 17.022% of the total variance and the greatest weights are for elements Rb, Sr, and Ba which indicates discussions related to weathering process. The third eigenvector constituted 11.939% of the total variance and presented the greatest weights for Ni and Cr which are important elements considering in sorting and compositional maturity. Meanwhile, the fourth eigenvector explained 5.926% of the total variance and presented the greatest weights for Co, and Cr which are good indicators for provenance studies.

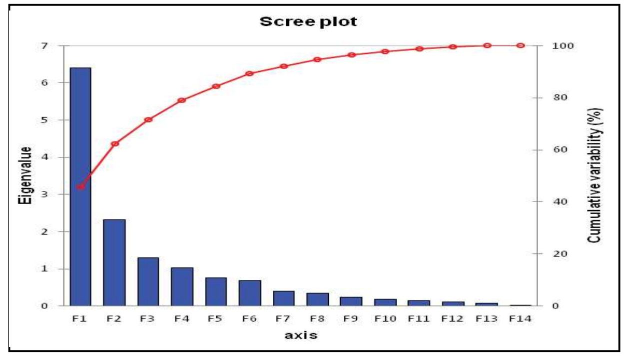

Figure 3a: Scree plot of final dataset for Trace Elements in Northern Bida Basin.

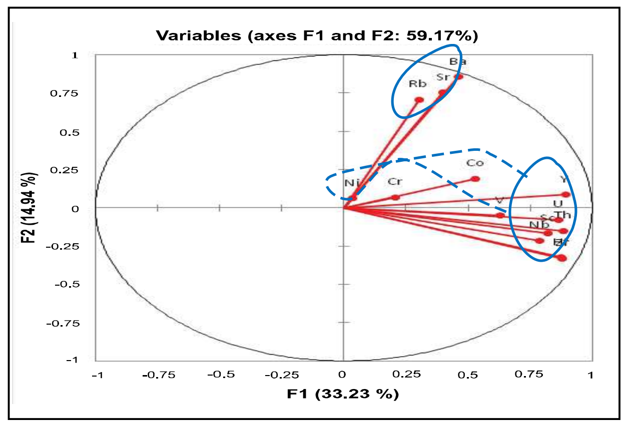

Figure 3b: Eigenvector plot of Trace elements within Northern Bida Basin showing the grouping of certain elements of similar geological processes.

CONCLUSIONS

The statistical analysis including Pearson Correlation Matrix, Factor Analysis and Principal Component Analysis were employed to study chemical data set of siliciclastic sediments in the northern Bida sub-Basin with the aim to provides an insight into the prevalent geological processes within the area during formation.

Pearson correlations matrix revealed highly correlated elements groups with relationships that deduced prevailing geological processes within the area.

Extracted factors with element associations (3 Factor for major oxides and 4 Factor for trace elements) from the data set represents the signature from depositional environment, weathering, sorting and maturity, with provenance studies respectively.

Principal Component Analysis of the sandstones generally resulted in 3 to 4 interpretable components with the recurring components of elements for depositional environment, weathering, sorting and maturity as well as provenance and tectonic settings. These geological processes suggest sediment contribution into the Basin primarily from continental sources by weathering and erosion from the surrounding Basement rocks.

These results give confidence in the fact that statistical treatment of the data sets gives geologically meaningful and reliable information, allowing the dominant geological processes controlling sediment composition at the Basin be inferred.

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