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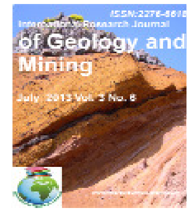

Full Length Research Paper

Geochemistry and provenance of sandstones from Anyaboni and surrounding areas in the voltaian basin, Ghana

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Abstract

Sandstones from the Middle Voltaian Oti-Pendjari Group in the Anyaboni and surrounding areas were analyzed for their major oxides and trace elements. The purpose of study is to infer their provenance and depositional tectonic setting. On the basis of their major element compositions the sandstones may be classified as either quartz arenite or subarkose. Discrimination diagrams based on major element geochemistry suggest that the sediments were derived from recycled sedimentary rocks. However, when the samples are normalized to average Neoproterozoic cratonic rocks they show enrichment in ferromagnesian trace elements such as Cr, Co and V which suggests some input from mafic source. Tectonic discrimination method based on major element geochemical data of sandstones suggests deposition in a passive continental margin.

Keywords: Geochemistry, Ghana, neoproterozoic, provenance, voltaian group.

INTRODUCTION

The chemical and mineralogical composition of clastic sedimentary rocks is controlled by the composition of their source rocks, environmental parameters influencing the weathering of the source rocks (e.g., atmospheric chemistry, temperature, rainfall, and topography), duration of weathering, transportation mechanisms of clastic materials from the source areas to the sites of deposition, depositional environments (e.g., marine versus fresh water), and post depositional processes (e.g., diagenesis and hydrothermal alteration).The geochemistry of sedimentary rocks therefore, reflects a combination of provenance, chemical weathering, hydraulic sorting, and abrasion (Taylor and McLennan, 1985; Wronkiewicz, and Condie, 1987; McLennan et al., 1993; Condie, 1993, Nesbitt et al., 1997). Furthermore, geochemical signatures of basin clastic sedimentary rocks provide important sources of information (Yan et al., 2007). In particular the use of immobile major and trace elements that are thought to be carried in the particulate load have been found to be useful indicators of source terrain, weathering, tectonic, and environmental evolution (Taylor and McLennan, 1985; Roser and Korsch, 1988, Cullers, 2000). Some trace elements including the rare earth elements (REEs) are relatively insoluble and as a result, their original compositions are not upset during the sedimentary processes.

The Voltaian Super group outcrops in the Volta Basin which is located east of the Leo-Man shield of the West African Cration (Figure 1). A subdivision of the stratigraphy of the Voltaian Basin into three groups is generally accepted. The Lower Voltaian Kwahu-Morago Group (estimated maximal thickness ~ 1500m) consists mainly of coarse-grained quartzitic and feldsparthic sandstones. It is unconformably overlain by the Middle Voltaian Oti-Pendjari Group (~ 3000m) which has tilloid beds and limestone at its base, and consists mainly of shales and greywackes (Kalsbeek et al., 2008). The Oti-Pendjari Group is unconformably overlain by the upper Voltaian Obosum Group (~ 1000m) which is largely composed of quartzitic and feldspathic sandstones of variable grain sizes.

Previous studies on provenance of the Voltaian Super group has been based on petrography and mineral chemistry of derived grains (Anani, 1999; Anani et al.,

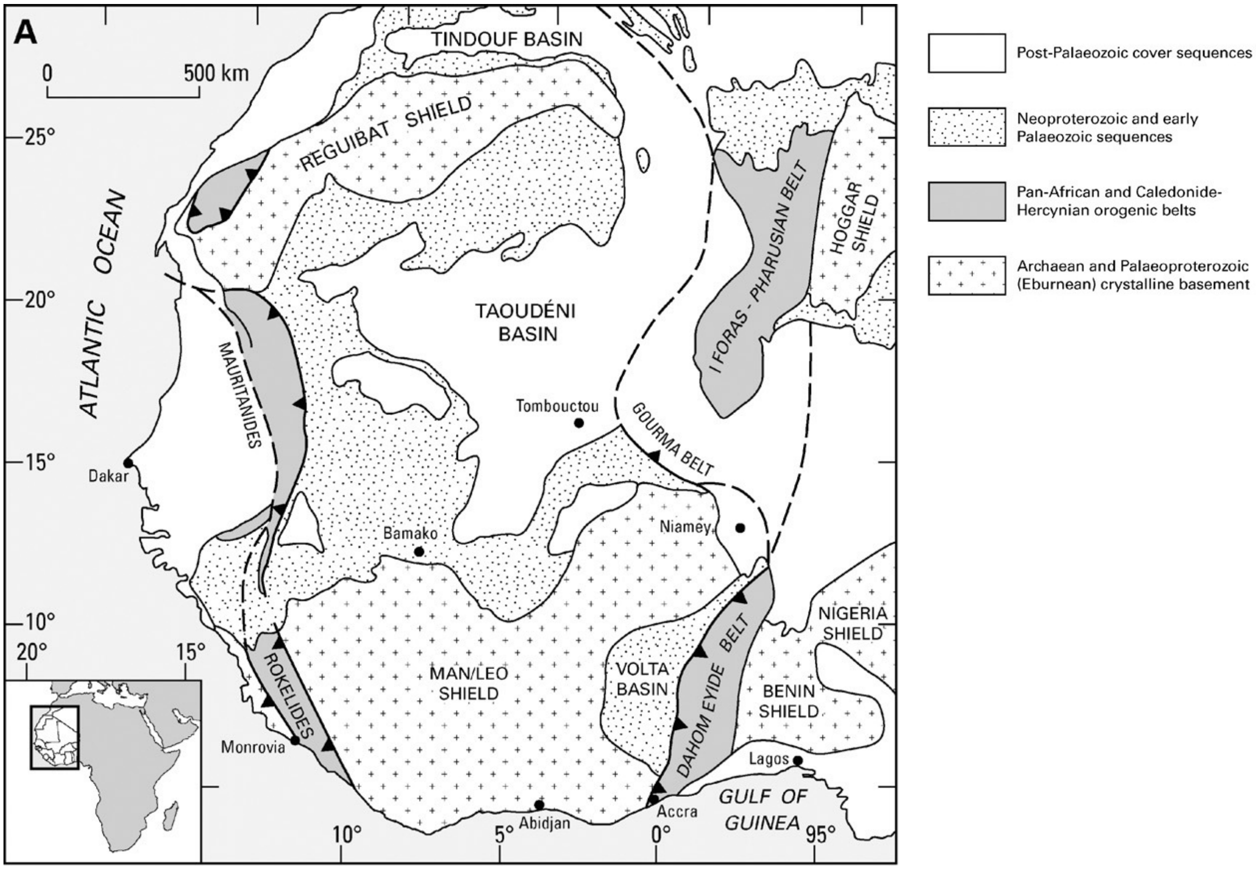

Figure 1. Simplified geological map of the West African Craton showing the Voltaian Group (After Carney et al., 2010)

2012a) and geochronology (Kalsbeek et al., 2008; Anani et al., 2012b).This study focuses on whole rock geochemistry to decipher the provenance and tectonic setting of sandstones from the Anyaboni and surrounding areas in the Middle Voltaian Oti-Pendjari Group. The study area lies in the southeastern part of the Voltaian Basin.

Geological Setting

The geological evidence suggests that the Voltaian Basin has a typical platform cover particularly on the western and central parts (Affaton, 1980; Wright et al., 1985). In fact over much of its outcrop area, Voltaian sediments are undisturbed; they have shallow dips (1-2º) to the east or south east, but near the eastern margin of the basin the rocks have been affected by Pan-African (~600 Ma) deformation and steeper dips (Kalsbeek et al., 2008). There are few detailed geologic descriptions of sediments of the Voltaian Super group sequences; subdivision of the Super group is difficult due to poor exposure and the lack of laterally persistent lithological marker beds or fossils (Anani, 1999).

The Voltaian Basin generally reflects different modes of deposition resulting in lithologically varying units. Carney et al. (2010) have interpreted the depositional environment of the basal sandstones of the Kwahu-Morago Group as being lacustrine or deltaic (marginal marine) conditions, which were superseded by fluvial channel environments as sea levels fell. In the Kwahu-Morago Group, tabular beds are laterally very extensive. Bed tops are scoured locally and some are weakly rippled and undulatory. The mature, very quartz-rich sandstone is interpreted to have been deposited by turbidity currents from a beach or delta system into deeper waters near to a shoreline, possibly due to storm activity. The Oti-Pendjari Group is medium- to coarse-grained, quartz-rich but locally with some feldspar. Thin trough cross beds in herring-bone form are prominently developed. Palaeo-currents towards the north and southwest have been interpreted to be of shallow marine (upper shore face) sandstone deposited under the influence of high energy tidal waters (Carney et al., 2010).Sandstones of the Obosum Group are highly immature in composition and are indicated by abundant feldspar and lithic grains. They are also medium- to coarse-grained, with sporadic 'floating' pebbles and pebble lags with paleo-current to west-southwest. The depositional environment is interpreted to be of very rapid deposition, poorly sorted and worked fluvial sandstone, probably deposited by flash floods or debris flowage in or adjacent to wadis. Such lithologies are typical of the terrestrial molasse, which was deposited during uplifts associated with the Pan-African orogeny farther east.

MATERIAL AND METHODS

Twelve (12) sandstone samples from the silicaclastic deposits of the Anyaboni and surrounding areas were studied in the present work. For a whole rock geochemical analysis, samples were formed into pressed pellets using standard preparatory techniques namely, (air dry, jaw crusher, sieve and shaker) then pellets prepared using a pellet presser. The pellets were then sent into an XRF machine (Spectro X-Lab 2000) for a period of about twelve hours for major and trace element geochemical analysis. The XRF analysis was carried out at the Ghana Geological Survey Department. Sandstone geochemical data was plotted following the classification schemes of Herron (1988). Composition of the major element oxides of the sandstone was used for provenance determination applying tectonic discriminatory plots of Bhatia (1983), McLennan et al. (1993) and Roser and Korsch (1988).

Sandstone Classification

Major and trace elements analyses of 12sandstone samples from Anyaboni and surrounding areas are listed in Table 1. It is apparent from the table that most of the samples are high in SiO_2 (85.0-97.5%, Average = 93.3%), and low inAl_2O_3contents (0.05-6.04%, Average = 1.9%), and a limit range of K_2O (0.12 – 3.0%; averaging 1.42%). In contrast, they possess low average contents of TiO_2, MnO, CaO, and Na_2O. Fe_2O_3 and MgO are also low and collectively sum to less than 5%.

The high K_2O/Na_2O ratios are attributed to the relatively common presence of K-bearing minerals such as K-feldspar and some micas (Kalsbeek et al., 2008; McLennan et al., 1983; Nath et al., 2000; Zhang, 2004; Osae et al., 2006). A positive correlation between K_2O and Al_2O_3 implies that the concentrations of the K-bearing minerals have significant influence on Al distribution and suggests that the relative abundance of these elements is primarily controlled by the content of clay minerals (McLennan et al., 1983). Based on these ratios, some of the sandstones samples can be classified chemically as sub-arkose, and sub-litharenite (Figure 2).These results are further supported by low Al_2O_3/SiO_2ratios which further helps to classify some of the samples as being quartz arenites (Figure 2) (Pettijohn et al., 1987).

Provenance

In the discrimination diagrams for sedimentary provenance after Roser and Korsch (1988), all samples of the studied sandstones, plot in the quartzose recycled field (Figure 3).

The discriminant functions of Roser and Korsch(1988) use Al_2O_3, TiO_2, Fe_2O_3, MgO, CaO, Na_2O, and K_2O contents as variables. These were designed to discriminate among four sedimentary provenances: Mafic - ocean island arc; Intermediate - mature island arc; Felsic - active continental margin; and Recycled –granitic, gneissic or sedimentary source. In this diagram (Figure 3), all the samples of Anyaboni and surrounding areas plot in the field of recycled continental sources associated with a passive continental margin, intracratonic sedimentary basins, and recycled orogenic provinces. Provenance discrimination diagrams based only on major elements are unreliable because of the mobilization of these components during weathering and alteration. Certain trace elements and REE are most suitable for the determination of provenance and tectonic setting (Bhatia, 1983; Taylor and McLennan, 1985; Bhatia and Crook, 1986), because of their relatively low mobility during sedimentary processes and their low residence time in seawater. These elements are generally thought to be quantitatively transported into clastic sedimentary rocks after weathering, and thus, they may reflect the signature of parent materials.

The Voltaian sandstones are enriched in trace elements as compared to the cratonic sandstone, with the exception of Th and Y which are low compared to the cratonic sandstones. The REE, Th and Sc are generally accepted as among the most reliable indicators of sediment governance because their distribution is less affected by heavy- mineral fractionation than that of elements such as Zr, Hf and Sn (Cullers, 1979; Taylor and McLennan, 1985). The alkali, large ion lithophile elements (LILE) and the high field strength element (HFS) abundances are generally higher in felsic igneous rocks and in their weathering products than in mafic rocks, whereas transition metals such as Co, Sc, Ni and Cr are more concentrated in mafic than in felsic igneous rocks. Figure 4 shows the range of concentrations of the analyzed samples normalized to average Proterozoic cratonic sandstone (Condie, 1993) which is felsic in composition. On this spider diagram the Voltaian sandstones show comparable concentrations with average cratonic shales by their LILE and HFS element suggesting dominantly felsic sources (Figure 4). However, the high concentration of the ferromagnesian trace elements such as Cr, Co and V compared to cratonic sandstone (Figure 4) suggest some contribution from mafic source.

Table1. Major and trace elements of the selected sandstone samples of the Anyaboniand surrounding areas

	CA 112	CA 128	CA 134	CA 136	CA 144	CA 151	CA 156	CA 165	CA 185	CA 199	CA 204	CA 208
in wt%												
SiO_2	97.5	97.5	93.3	85.0	98.0	90.7	93.0	96.1	89.4	92.7	94.4	92.3
Al_2O_3	0.05	0.05	1.67	6.04	0.05	2.25	2.41	0.33	3.96	1.94	1.60	2.16
TiO_2	0.04	0.03	0.45	0.50	0.03	0.82	0.13	0.11	0.08	0.61	0.09	0.18
Fe_2O_3	0.23	0.37	1.15	1.84	0.16	1.34	0.32	0.58	1.43	0.90	0.25	0.65
MgO	1.34	1.60	1.98	1.83	1.27	1.73	1.45	1.77	1.58	1.19	1.70	1.60
MnO	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01
Na_2O	0.63	0.21	0.34	1.37	0.20	1.31	0.75	0.62	0.80	0.20	0.32	0.68
K_2O	0.12	0.16	0.93	3.00	0.23	1.78	1.87	0.32	2.54	2.32	1.55	2.27
CaO	0.01	0.01	0.05	0.04	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.02
P_2O_5	0.08	0.08	0.06	0.30	0.07	0.06	0.08	0.07	0.19	0.06	0.06	0.12
SO_3	0.01	0.01	0.03	0.05	0.00	0.04	0.03	0.03	0.03	0.03	0.00	0.04
in ppm												
Rb	5.60	7.10	24.2	64.4	6.30	68.6	41.1	57.2	54.3	59.5	38.1	50.0
Ba	22.7	22.6	73.9	483	22.4	338	195	336	276	345	178	257
Sr	9.20	5.80	20.4	97.8	5.80	29.8	22.2	24.5	23.0	26.2	19.6	57.0
Cs	6.40	6.50	6.60	6.90	6.20	6.90	8.40	6.40	6.60	6.80	6.40	6.50
Zr	59.4	27.0	177	179	33.0	228	64.4	55.7	55.1	171	59.9	121
Hf	10.0	14.7	18.7	13.8	10.6	13.7	9.40	8.40	9.10	13.3	7.60	9.20
Ta	4.90	5.20	6.50	6.20	4.00	4.20	4.20	4.20	4.20	5.70	3.80	4.20
Nb	3.00	2.60	7.00	9.70	2.80	15.5	4.40	3.70	3.00	10.7	2.20	3.10
Th	1.60	1.40	5.40	9.50	1.20	11.1	0.80	1.30	0.80	5.10	1.20	3.60
U	5.20	4.50	6.50	6.70	5.20	7.30	6.70	6.70	6.80	6.80	5.50	6.30
Y	0.90	0.80	4.40	19.3	0.80	7.10	0.80	9.60	2.00	4.20	0.80	4.90
La	16.7	14.0	29.2	35.2	14.0	18.0	15.9	25.3	14.0	25.0	12.3	21.3
Ce	26.8	19.0	34.0	81.2	19.0	38.6	37.6	42.1	19.0	40.8	24.1	40.4
V	150	130	340	370	140	460	210	210	230	450	210	240
Cr	618	105	100	1044	770	493	338	135	591	400	640	184
Co	11.0	12.0	18.0	23.0	7.60	19.0	9.40	12.0	19.0	14.0	7.90	12.0
Ni	5.70	7.80	10.6	16.7	8.90	10.0	8.00	8.50	6.10	8.60	7.80	10.0
Cu	2.70	2.70	2.60	2.80	2.20	2.50	3.80	2.80	1.70	2.20	2.80	4.40
Zn	4.40	4.40	10.0	19.1	4.00	9.20	5.20	6.60	9.10	5.80	2.80	14.0
Ga	2.50	2.50	4.40	7.40	3.50	6.30	3.80	4.90	4.50	3.60	4.00	7.20
Pb	5.30	4.40	8.00	11.7	1.30	13.5	5.30	6.10	7.70	9.50	4.30	4.50

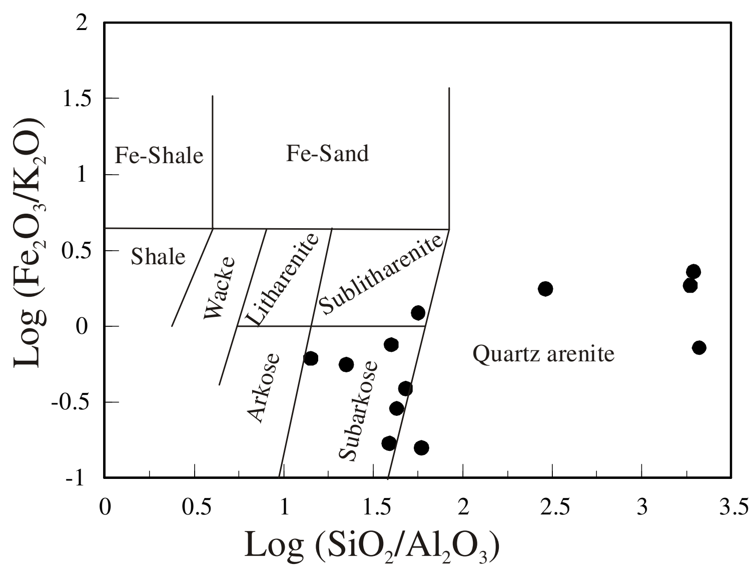

Figure 2. Chemical classification of sandstone samples from Anyaboni and surrounding areas based on binary diagrams; log (SiO_2/Al_2O_3) versus log (Fe_2O_3/K_2O) diagram of Herron (1988)

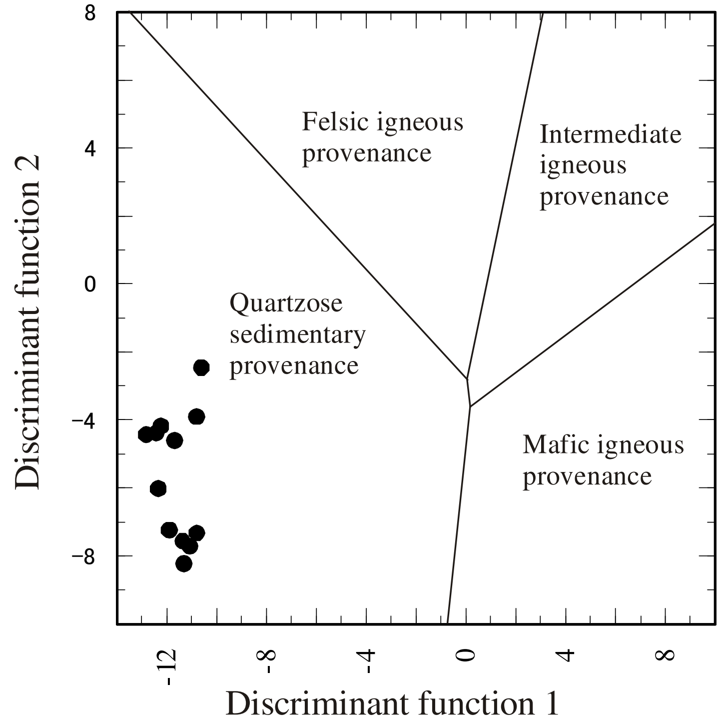

Figure 3. Provenance discriminant function diagram using major elements in sandstones from Anyaboni and surrounding areas after Roser and Korsch (1988

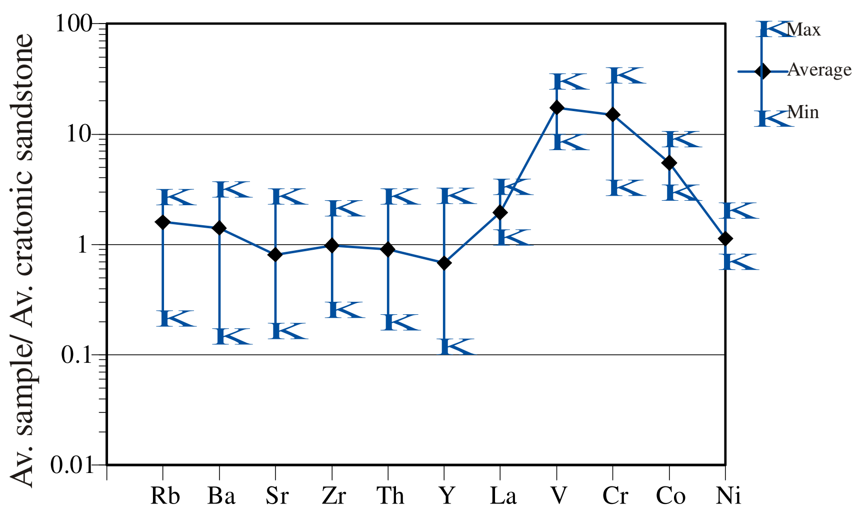

Figure 4. Average Proterozoic Cratonic sandstone- normalized patterns for sandstones samples from Anyaboni and surrounding areas in the Voltaian Super group. Normalizing values after Condie (1993)

Tectonic Setting

Several studies have shown that the chemical compositions of clastic rocks are significantly controlled by plate tectonic settings of their provenances, and consequently clastic rocks from different tectonic settings possess terrain-specific geochemical signatures (Bhatia, 1985; Roser and Korsch, 1988). Three tectonic settings, the passive continental margin (PM), active continental margin (ACM) and oceanic island arc (ARC) are

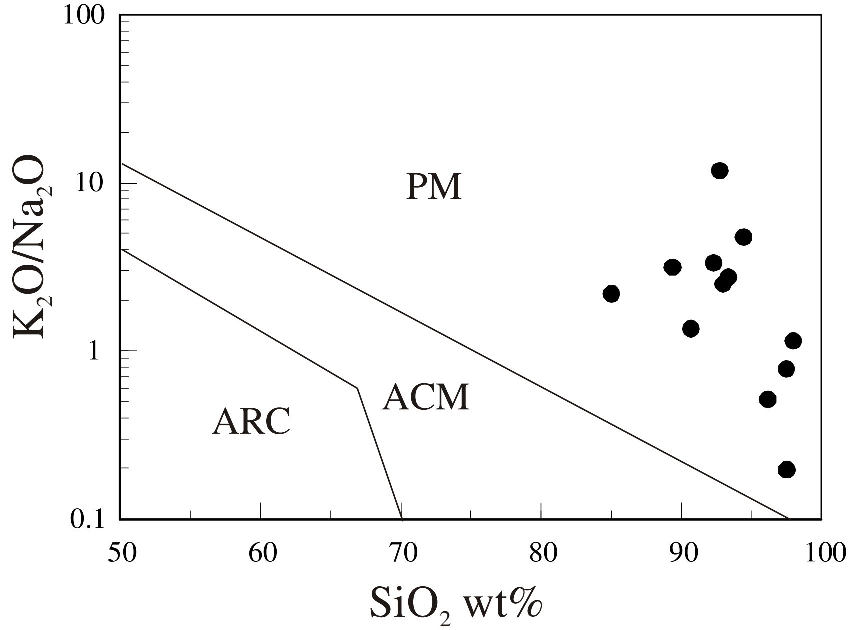

Figure 5. Tectonic discrimination diagrams based on major oxides of the sandstone samples of Anyaboni and surrounding areas after Roser and Korsch (1988).(PM, passive continental margin; ACM, active continental margin; ARC, oceanic island arc)

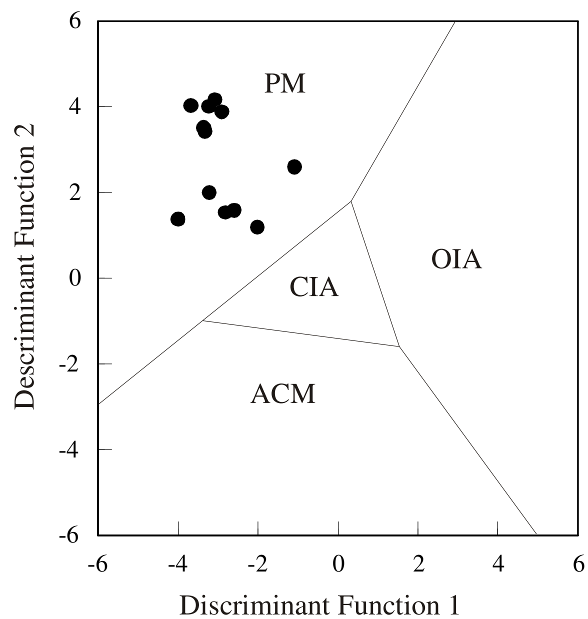

Figure 6. Plots of the major element composition of sandstones of Anyaboni and surrounding areas on the tectonic setting discrimination diagrams of Bhatia (1983)

Recognized on the (K_2O/Na_2O)–SiO_2 discrimination diagram of Roser and Korsch (1988). The sandstones of Anyaboni and surrounding areas are characterized by high K_2O/Na_2O ratios and are deposited in a passive continental margin (Figure 5). This result is further supported by plotting chemical contents of the studied sediments on the discrimination diagram of Bhatia (1983) (Figure 6) where the samples fall within the Passive margin field.

CONCLUSION

A geochemical study had been carried out on sandstones of the Anyaboni and its surrounding areas, in the southeastern part of the Voltaian Supergroup of Ghana. The inference was to decipher their geochemical characteristics, source rocks and tectonic setting.

1. Major oxides and trace elements indicate that these sandstones were derived from felsic source rocks, probably a quartzose recycled provenance from plate interior or stable continental areas. The tectonic setting discrimination diagrams, support a passive continental margin for the sandstones of Anyaboni and its surrounding areas;
2. Research progress (including Sm-Nd and other geochemical study, etc.) (Kalsbeek, 2008; Anani et al., 2012a, b) of the Neoproterozoic Voltaian Supergroup, Ghana, as well as the study therein, indicates a granitic, gneissic or sedimentary sources, suggesting supply of sediments from the nearby Birimian Supergroup and some possible contribution from the Pan-African rocks.

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